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The Effect of Rate Change on the Relative Timing of Speakers with Multiple Sclerosis

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by

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Abstract

Relative timing ratios are a useful measure for determining the temporal regularities of speech. The timing intervals that make up these ratios are thought to be important when creating the motor plan for an utterance (Weismer & Fennell, 1985). In fact, these ratios have been shown to be remarkably stable, even when speakers deliberately increase their rate (Tuller & Kelso, 1984; Weismer & Fennell, 1985). The constancy of these ratios also has been demonstrated in speakers with known speech timing disturbances, like the dysarthrias associated with Parkinson's and Huntington's disease (Goberman & McMillan; Ludlow, Connor, & Bassich, 1987; Weismer & Fennell, 1985), apraxia (Weismer & Fennell, 1985), and stuttering (Prosek, Montgomery, & Walden, 1988). However, a slowed rate of speech has been noted to induce variability in relative timing (Clark, 1995). The current investigation was designed to further investigate the impact of a slow rate on relative timing, as well as the impact of a different type of dysarthria on the production of these ratios.

Eleven participants with MS and ten healthy controls participated. After screening the participants with MS for cognitive abilities and degree of dysathria, they produced four sentences at three different rates of speech: conversational, fast, and slow. Age-matched controls only provided the rate-controlled sentences. Relative timing ratios were extracted and an analysis of variance was conducted for each sentence to note the effects of speech rate, ratio type, and speaker condition on relative timing.

The results revealed that relative timing was not constant in the slow rate for any of the participants. The noted variability in slow speech was attributed to vowel characteristics and sentence length. Finally, people with MS demonstrated larger relative timing ratios than their healthy peers when producing lengthier or motorically complex sentences.

Consistent with previous research (Clark, 1995), these results indicated that relative timing ratios were not constant when rate was slowed. Hence, use of a reduced rate may have triggered the critical change required to alter relative timing. This difference may also correspond to a topological shift in the cortical planning of the utterance. These findings provide support for the use of slowed speech in the treatment of dysarthria and other speech timing disorders. It may be that slowed speech allows the speaker to access a motor plan better suited to his impaired muscular system.

Chapter One: Literature Overview

Although similar to other types of motor processes (Wallace, 1989), speech production is a more precise, complex, and rapid motor process that is constrained by our need to have speech understood (Bent, Bradlow, & Smith, 2008; Byrd, 1996; Fink, 1986; Kent, 2000; Kent & Rosen, 2004; Lofgvist, 1994). Listeners rely on the duration of segments (Klatt, 1976), as well as the coordination and transitions between segments to interpret speech signals (Byrd, 1996; Neel, 2008). An example of this is the distinction between the phrases “an aim” and “a name” (Haugen, 1949). Differentiation of the two phrases depends upon the timing of the production. Thus, timing plays a crucial role in the production of intelligible speech.

Several acoustic methods exist to analyze the timing characteristics of speech (Kent, Kent, Weismer, Vorperian, & Duffy, 2000). For example, relative timing ratios are a useful measure to determine the temporal regularities of an utterance. These ratios require the creation of a period of articulatory activity and the latency of an articulatory event within that period. The timing intervals that make up these ratios are thought to be important when creating the motor plan for an utterance (Weismer & Fennell, 1985). Specifically, the transitions from a consonant to a vowel (CV) or a vowel to a consonant (VC) are noted to be anchor points around which other movements are organized (Schaffer, 1982; Weismer & Fennell, 1985). Timing intervals are created with these CV or VC points serving as boundaries. Ratios are then created from sets of overlapping intervals. As such, these ratios are presumed to reflect cognitive planning.

The timing of an utterance is constrained by the parameters of fluent speech. For this reason, the relative timing ratios of a fluent utterance have little room for variance and have been shown to be constant across rate change for various types of speakers (Baum & Boyczuk, 1999; Clark, 1995; Gracco, 1988; Goberman & McMillan, 2005; Ludlow, Connor, & Bassich, 1987; Max & Caruso, 1997; Robb & Pang-Ching, 1992; Weismer & Fennell, 1985). The constancy of these ratios reflects the inherent organization of the motor system. To better understand the role of these ratios, several current models of speech production will be described below.

Models of speech production

Two of the most common frameworks are the generalized motor program (Duffy, 2005; Heuer, 1988) and the dynamic systems model (van Liesholt, 2004). The generalized motor program model of speech production asserts that motor plans are created as speech is learned and are stored in the brain as engrams for later retrieval. These general plans define the invariant aspects of movement (Maas, et al., 2008), including the relative timing of an utterance. To plan an utterance, the brain maps situation-specific parameters (e.g., the absolute duration of the utterance) onto the existing schema. Minor online modifications are made to the speech plan according to sensory feedback, but the invariant characteristics of the utterance (e.g., the relative timing) occur as dictated by the engram (Duffy, 2005).

Similarly, the dynamic systems model describes relative timing as intrinsic to the speech system but refutes the notion of a central, static plan of speech production. Instead, this model describes an abstract, task-specific gestural activation pattern. This pattern is retrieved and then mapped on to the specific vocal tract dimensions of the speaker. The timing of the gestures then is modified according to language-specific linguistic boundaries and the speaker's preferred speaking style (van Lieshout, 2004). These patterns are dictated by the needs and context of the moment (Maassen, van Lieshout, & Pascal, 2010), and are constrained by the intrinsic properties of the system, including relative timing (Schöner, 2002).

These two competing models are brought together in the continuity theory (Heuer, 1988). While these earlier theories assert that relative timing remains completely invariant across rate change (Duffy, 2005; van Liesholt, 2004), the continuity theory allows for graded differences between inter-gestural time intervals. Accordingly, the continuity theory asserts that minor changes in relative timing across rate change indicate adjustments that occur along the speech chain (Denes & Pinson, 1963), moving from the cortex to the articulators. These adjustments may be required because of anatomical constraints or preferences and reflect the flexibility required in a complex system (Byrd, 1996; Heuer, 1988, 1991). In this model, the constancy of relative timing is a strategic choice that is made *most* of the time, but motor control also allows for adjustment of timing to fit the needs of the speech task at hand (Heuer, 1988). However, these minor changes in relative timing across rate changes are dwarfed by the obvious tendency towards invariance (Heuer & Schmidt, 1988).

Relative timing across speakers

Early research in motor timing focused on non-speech motor movements, such as typing or limb movements (Byrd, 1996; Terzuolo & Viviani, 1980; Viviani & Terzuolo 1982). These studies found that relative timing remained constant for fast and habitual rates during the execution of these motor activities. However, interest soon turned to the role of relative timing in speech.

Relative timing in normal speakers. Tuller and Kelso (1984) established the constancy of relative timing at the syllable level in their study of normal speakers. They sought to determine whether relative timing would systematically change when suprasegmental characteristics (i.e., stress and rate) were altered. Electromyographic (EMG) activity was used to measure kinematic movements of the lip and jaw while participants uttered bisyllabic, nonsense CVCVC words at conversational and fast rates. To calculate relative timing, overlapping intervals were chosen that reflected the articulatory movements necessary for the production of consonants or vowels (i.e., “vowel cycles” or “consonant cycles”). The duration of “consonant-specific movements” was divided by the duration of vowel-specific movements. Comparison of these measures showed a high correlation among utterances (ranging from 0.92 to 0.94), even those that differed in rate and stress. Results indicated that relative timing was characterized by an obvious tendency towards invariance (Heuer & Schmidt, 1988). Similarly, EMG studies of lip perturbations (i.e., movement displacement) during the utterance of nonsense words have shown that the articulators will adjust their movement velocity to maintain relative timing across rates (Gracco, 1988).

Weismer and Fennell (1985) tested these findings at the phrase level using the sentence *Bob hit the big dog.* Three young, typically developing participants spoke the sentence at conversational and fast rates. Timing ratios were created from a set of seven intervals that were thought to be meaningful to the planning and execution of the utterance (Weismer & Fennell, 1985). Each interval began at the burst of the initial /b/

and ended at a consonant-vowel interface at a further point in the utterance. From these durations, ratios were created to assess the constancy of relative timing when rate was increased. Results indicated that relative timing was constant despite rate change in these healthy speakers.

While these studies examined relative timing for fast and conversational rates, little is known about the effect of slowed rate on relative timing. To this end, Clark (1995) examined relative timing as a function of fast, conversational, and slow rates of speech for healthy, young speakers. Four relative timing measures were created for a set of five standard test phrases according to the procedures outlined in Weismer & Fennell (1985). These included three sentences that primarily consisted of obstruent phonemes (Smith, Wasowicz, & Preston, 1987; Weismer & Fennell, 1985) and two sentences that consisted primarily of sonorants (Rabiner, Schafer, & Flanigan, 1971). Since the intervals were made up of transitions between consonants and vowels, the researchers sought to include sentences that included "fluid" transitions (i.e., sonorants) and less "fluid" transitions (Clark, 1995).

Results indicated that relative timing remained constant for fast and conversational rates but varied when rate was slowed (Clark, 1995). It was proposed that when a speaker decreased the absolute duration of an utterance, the relative timing was reorganized in an attempt to maintain the intended emphatic stress of the utterance. In addition, the investigator hypothesized that slowed rate may be programmed in a different cortical area than fast and conversational rates. The idea that slow speech requires a different motor plan than fast or normal speech is supported by research showing that motor patterns for the articulatory gestures of slow speech are different from those generated for fast speech (Gay & Hirose, 1973; Gay & Ushijima, 1975).

The idea that slowed speech results in a change to relative timing also fits in with catastrophe theory, a biological theory that can be applied to the production of speech (Kugler, Kelso, & Turvey, 1982). Catastrophe theory asserts a division between "essential" and "nonessential" variables in the planning of motor movements (Kugler, et al., 1982). In speech, the essential variable would be relative timing, while the nonessential variable would be speech rate. Essential variables (i.e., relative timing) are intrinsic to the motor movement and cannot be changed without changing the topological qualities of the plan (i.e., location of processing in the motor cortex). Nonessential variables (i.e., speech rate) can be altered slightly without changing the location of processing. However, these authors assert that a continuous change to a nonessential variable would result in a topological change when planning the utterance. This change in location of processing would also alter the essential variables. Therefore, a continuous change in speech rate (i.e., the nonessential variable) could result in a change in relative timing (i.e., the essential variable). However, this change in rate must reach "critical value" in order to activate a change in relative timing (Weismer & Fennell, 1985).

It is important to note that these studies included speakers with normal motor planning abilities. An important test of this theory would be what happens in the disordered system – if relative timing is truly intrinsic to the utterance, then speaker characteristics should not affect the constancy of relative timing measures. Hence, the bulk of recent research in relative timing has examined the role of relative timing in impaired speakers.

Relative timing in impaired speakers. In the same study that established the constancy of relative timing for healthy speakers, Weismer & Fennell (1985) explored the role of relative timing in a second group of participants made up of neurologically impaired speakers (i.e., Parkinson's disease, spastic cerebral palsy, and apraxia). In their study, participants uttered five phrases at both conversational and fast rates. Four relative timing measures were created for each sentence and the ratios were compared across rates. Interestingly, their results revealed that relative timing was constant for each group of speakers, even though their speech was marked by temporal irregularities (i.e., shorter or longer segments, word, phrase, or pause durations) (Weismer & Fennell, 1985).

In a similar study, Ludlow, Connor, and Bassich (1987) examined the relative timing of speakers with Parkinson's and Huntington's disease. These diseases, which result from lesions in the basal ganglia, are noted for disturbances in the rhythm and timing of motor movements. Speech production in these patients typically is characterized by longer pauses between words than in normal speech. Relative timing was calculated by comparing timing ratios from spectrograms of the utterance "did he go right or left", produced at conversational and fast rates. Though the impaired speakers had reduced control over their rate of speech, their relative timing ratios remained constant despite rate change. Similar results were found in another study that showed that nine participants with Parkinson's disease displayed invariant relative timing (Goberman & McMillan, 2005).

Further evidence that relative timing is an intrinsic property of speech production comes from research with hearing impaired (HI) individuals. Speakers with a hearing impairment have been shown to display aberrant speech timing, including increased overall duration of utterances and within-utterance pauses (Stathopoulous, Duchan, Sonnenmeier, & Bruce, 1985; Tye-Murray, 1987). To determine the effect of this abnormal timing on the constancy of relative timing ratios, twenty-six otherwise healthy young adults with a severe-to-profound, prelingual hearing loss were tested (Robb & Pang-Ching, 1992). Intelligibility for these HI speakers was rated between 2 (good) and 4 (moderately unintelligible) on a 5-point scale. Four relative timing ratios, based on Weismer & Fennell's (1985) methods, were calculated for the phrase "boiling pot of gold" and compared to the relative timing of age-matched controls. Though the HI group exhibited speech errors characteristic for that population (e.g., voicing errors, vocalic nasalization), results indicated that the relative timing for the two groups was similar.

Another group that displays disordered timing in speech is people who stutter. Prosek, Montgomery, and Walden (1988) compared the fluent utterances of people who stutter to those produced by people without a fluency disorder. Results revealed that fluent utterances were produced with constant relative timing regardless of whether the speaker had a fluency disorder or not. They found that even in utterances surrounded by dysfluencies, the speech system readjusted to maintain the necessary timing intervals for fluent utterances. This finding supports the idea that the production of fluent speech acts as a constraint on the possible temporal patterns of an utterance (Weismer & Fennell, 1985) involving both central (i.e., cognitive) and peripheral (i.e., speech articulator) processes (Robb & Pang-Ching, 1992; Weismer & Fennell, 1985).

Similar to the studies discussed above, research has indicated that people with aphasia, right-hemisphere disorder, and basal ganglia diseases (e.g., Parkinson's and Huntington's disorder) also display constant relative timing for the fast and conversational rates (Baum & Boyczuk, 1999; Ludlow, et al., 1987). However, little is known about the effect of multiple sclerosis on the constancy of relative timing measures. Given that temporal dysregulation is characteristic of the dysarthria displayed by people with multiple sclerosis, inclusion of this group may add to the body of research about relative timing in the impaired speaker.

Multiple Sclerosis

Multiple sclerosis (MS) is an acquired disease of the central nervous system (CNS) characterized by primary demyelination of neuronal axons with relative sparing of the axon itself, though axonal damage has been noted in later stages (Corey-Bloom & David, 2009). The disease affects 400,000 people in the U.S., most often in Caucasian women of Northern European ancestry (DeLuca & Nocentini, 2011). The course of MS is variable, but generally fits into one of four patterns: 1) relapsing-remitting (i.e., periods of acute demyelination and symptoms alternating with periods of neurological repair and recovery), 2) primary progressive (i.e., steady worsening of symptoms), 3) secondary progressive (i.e., a period of steadily worsening symptoms that follows a period of relapsing-remitting symptoms), and 4) progressive relapsing (i.e., steadily declining neurological functioning delineated by periods of worsening) (Lublin & Reingold, 1996).

It is estimated that 40-51% of people with MS will exhibit dysarthria in their lifetime (Hartelius, Runmarker, & Andersen, 2000; Hartelius & Svensson, 1994; Yorkston, Klasner, Bowen, Ehde, & Gibbons, 2003). Dysarthria in MS is not correlated with a diagnostic profile, but with the severity and extent of cerebral damage (Hartelius, et al., 2000). It is strongly correlated with the appearance of cognitive-linguistic deficits

(Mackenzie & Green, 2009) and often appears alongside reading, writing, and visual difficulties, as well as concomitant fatigue and depression (Yorkston, et al., 2003).

Though a heterogeneous group, MS patients will most often display a mixed spastic-ataxic dysarthria that worsens with the progressive demyelination that characterizes the disease. The hallmark of ataxic dysarthria is temporal dysregulation, characterized by lengthened and equalized syllable durations. Because this group lacks the motor control to change syllable durations, their speech has been described as "scanning" (Hartelius & Lillvik, 2003; Henrich, Lowit, Schalling, & Mennen, 2006). Some MS patients will exhibit a concomitant variability in syllable and segment durations (Ackerman & Hertrich, 1994). A discussion of relative timing in the speech of people with MS may reveal subtle changes in speech timing that may occur before overt symptoms of dysarthria appear. Detection of these changes may lead to a better classification of speech deterioration in people with MS.

Statement of the Problem

Further research into the nature of relative timing in the dysarthria of MS will provide information that is both clinically and theoretically relevant. Previous research has investigated the constancy of relative timing across fast and conversational rates for groups of both normal and disordered speakers (Baum & Boyczuk, 1999; Ludlow et al., 1987; Robb & Pang-Ching, 1992; Weismer & Fennell, 1985). However, few studies have examined the effect of slowed rate on relative timing measures in healthy speakers (Clark, 1995). Additionally, while the research has included a variety of disordered speakers, little attention in this line of study has been paid to speakers with dysarthria.

Because the mixed spastic-ataxic dysarthria most often seen in MS is characterized by rhythmic disturbances, this disorder may offer interesting insight into the study of the constancy of relative timing in normal speech motor control. Additionally, comparison between rates of speech produced by speakers with MS may reveal differences in relative timing that contribute to increased intelligibility when rate is reduced, filling a gap in current evidence (Yorkston, Hakel, Beukelman, & Fager, 2007). An improved understanding of the timing breakdown in MS speech may lead to more precise guidelines for assessment and intervention. Given the potential for temporal dysregulation (Ackerman & Hertrich, 1994; Hartelius & Lillvik, 2003; Henrich et al., 2006) in the speech of patients with MS, an investigation of relative timing in this population seems warranted. Similarly, given that most previous research in has not included the slow rate, the current study seeks to answer the following questions.

1. Does the relative timing of speech remain constant when a speaker with multiple sclerosis alters his rate of speech to include fast and slow rates?
2. How does the relative timing of speech of speakers with multiple sclerosis compare to the relative timing of age-matched normal speakers?

Chapter Two: Methods

This purpose of this study was to examine the constancy of relative timing measures at conversational, fast, and slow rates of speech in patients with MS and age and gender-matched controls. Previous research has shown that relative timing is invariant in the fast and conversation rate (Weismer & Fennell, 1985), but is more susceptible to variation when rate is slowed (Clark, 1995). Additionally, this study sought to expand on the body of research that examines the constancy of relative timing measures in impaired speakers (Baum & Boyczuk, 1999; Gracco, 1988; Goberman & McMillan, 2005; Ludlow et al., 1987; Max & Caruso, 1997; Robb & Pang-Ching, 1992; Weismer & Fennell, 1985). The current study included speakers with multiple sclerosis and compared their relative timing ratios to age-matched, healthy adults.

Participants

The research coordinator of the Multiple Sclerosis Center at the Carol and Frank Morsani Center at the University of South Florida gave the principal investigator (PI) permission to recruit MS participants from the Neurology clinic. The nurse practitioner at the Neurology clinic identified potential volunteers and introduced them to the PI after their regularly scheduled appointments. The purpose and methods of the study were then explained to the patient and s/he was asked to participate. If interested, the patient was asked to complete the informed consent process and the testing was initiated.

In addition, letters describing the study were provided to local support groups for individuals with MS. These individuals then contacted the PI if s/he was interested in participating. Once contacted, the PI explained the project and set up an appointment with the interested individual. The informed consent process was completed at the time of testing.

Speakers. Eleven MS patients (10 females and 1 male) participated in this study. All but one of the volunteers were monolingual speakers of English without any significant cognitive impairments, health issues, or structural impairments of their speech production mechanism that would preclude their ability to complete the speaking tasks. One female participant with MS was a native German speaker, but was judged to be proficient in English. All speakers with MS had never undergone any neurosurgical intervention for their MS. They ranged in age from 47-62 years old, with a mean age of 55 years. All MS participants were classified as having a relapsing-remitting course of the disease by their neurologist. Length of time since diagnosis ranged from 2-28 years, with a mean of 11.8 years. Specific information about each participant with MS is included in Appendix A. Information about any prescription medication taken at the time of testing, as well as possible speech side effects, are listed in Appendix B.

Ten age- and gender-matched control speakers were recruited by placing flyers in the Department of Communication Sciences & Disorders at the University of South Florida. Participants ranged in age from 51-62 years old and reported that they were free of neurological or respiratory diseases that could affect speech production.

Listeners. To assist in the rating of the intelligibility of all speakers, four trained listeners were recruited from among the graduate student clinicians in the Department of Communication Sciences and Disorders at the University of South Florida. All volunteers had clinical experience in rating the voices of patients with dysarthria.

Materials

Participants with MS were assessed using the *Mini-Mental State Examination* (Folstein, Folstein, & McHugh, 1975). Participants with MS also took part in an interview about their diagnosis and medical history (See Appendix C for the question list). The participants with MS were audio-recorded using stimulus materials from the *Assessment of Intelligibility of Dysarthric Speech* (Yorkston, Beukelman, & Traynor, 1984), the Grandfather Passage (van Riper, 1963), and relative timing test phrases. The control group was recorded speaking the relative timing phrases. Each assessment tool is described below.

***Mini-Mental State Examination* (MMSE).** The *Mini-Mental State Examination (MMSE)* (Folstein et al., 1975) is an 11-question screening tool that assesses five areas of cognitive function: orientation (i.e., awareness of time, place and person), registration, attention and calculation, recall, and language. The MMSE assesses orientation to time and place in both broad scope (e.g., the season or the state) and narrow scope (e.g., month or floor of the hospital). Registration refers to the ability to retain incoming information in modality-specific form (e.g., spatial, tactile, auditory, etc.). The attention and calculation task requires the participant to count backwards from 100 by sevens (e.g., "100, 93, 86…"), while the recall task requires the participant to remember three unrelated words over a short period of time. Finally, the language task requires them to name common items in the environment (e.g., pen, watch, etc.) (Brookshire, 2007). Because seven of the eleven questions have additional sub-questions, the total possible score is 30. A score of 24-30 is indicative of "no cognitive impairment", while a score of 18-24 indicates a mild cognitive impairment. A score of 17 or below indicates a severe cognitive impairment. Validity and reliability was established with the administration of the MMSE to 206 people with cognitive disorders (i.e., dementia, pseudodementia, personality disorders, mania, and schizophrenia) and 62 healthy participants. Pearson product-moment correlation coefficient scores indicated excellent test-retest reliability with an intra-judge reliability of *r= 0.88* and inter-judge reliability of *r= .827*. Pearson product-moment correlation coefficient scores also indicated excellent construct validity with the *Wechsler Adult Intelligence Scale* (Wechsler, 1981): Verbal IQ (*r= 0.78)* and Performance IQ (*r= 0.66)* (Folstein et al., 1975).

Assessment of Intelligibility of Dysarthric Speech. The *Assessment of Intelligibility of Dysarthric Speech* (Yorkston, et al., 1984) is a widely used means for quantifying the intelligibility of dysarthric speech at the single-word and sentence levels, as well as for calculating an overall speech rate in words per minutes (wpm). At the single-word level, this test provides 50 sets of 12 similar-sounding words (600 words total). The participant is recorded reading or imitating a word from each set of similarly sounding words. Similarly, the sentence intelligibility task requires the participant to be recorded reading or imitating two 5- to 15-word sentences (up to total 220 words) randomly chosen from a pool of 200 sentences. The recordings are later played to a naïve listener. For assessment at the single-word level, the listener identifies the word s/he has heard from the set of 12 in a multiple-choice format. At the sentence-level, the listener transcribes the sentence as heard. From this transcription, a percentage of words correct is calculated that represents an intelligibility score. Speaking rate is calculated by dividing the number of words in the sentence sample (220) by the duration of the sample. To calculate the communicative efficiency ratio, the test speaker's rate is divided by 190 (the mean rate for speakers who are 100% intelligible) (Duffy, 2005). For the purposes of this study, intelligibility was only assessed at the sentence level. Because the test distinguishes between intelligibility at the sentence and the word-level, use of only one measure will not invalidate the score. The test-retest reliability of the sentence measure is excellent, with intra-judge reliability of $r= 0.99$ and inter-judge reliability of $r= .94$ (Yorkston, Beukelman, & Traynor, 1984).

Visual Analog Scale (VAS) of Speech Severity: Grandfather Passage. Though not a formal published assessment of speech, the *Visual Analog Scale (VAS) of Speech Severity: The Grandfather Passage* (Sussman & Tjaden, 2012) is a measure that has been previously used in research with speakers with MS and has shown to be sensitive to changes in speech resulting from progressive neurological impairments (Sussman & Tjaden, 2012). For this task, participants with MS were recorded reading the *Grandfather Passage* (Van Riper, 1963), a commonly used reading passage for evaluating speech production. Four second-year graduate students in speech-language pathology served as listeners. They were unaware of the diagnosis of the speakers and were asked to rate the impairment level of the ten speakers on a 100 mm VAS. The left end of the scale (0) represented "No Impairment", while the right end ("1") represented "Severe Impairment". After reading the instructions (see Appendix D), the listeners scored the recorded sample of the Grandfather Passage. They then marked the point on a 100-millimeter vertical line that corresponded with the severity rating of each speaker (Sussman & Tjaden, 2012).

Test Phrases. Four test phrases were recorded for this experiment. These four sentences are standard test phrases taken from previous investigations. The first three sentences were taken from a study by Weismer & Fennell (1985) and the fourth sentence was from Smith, Wasowicz, and Preston (1987). The stimuli were as follows:

1) The potato stew is in the pot.

2) Bob hit the big dog.

3) Bess bought a book on cooking soup.

4) Buy Bobby a puppy.

The sentences differed in phonemic content, sentence length, and number of consonant-vowel (CV) or vowel-consonant (VC) transitions. Sentences 1-3 consisted mainly of plosives and fricatives while sentence four consisted primarily of plosives. Secondly, sentence length ranged from four to seven words. Another important difference between sentences was the number of CV or VC transitions (e.g., the release of a /p/ into a /o/). These transitions were used as demarcation points for the relative timing ratios and ranged from nine to eighteen points in the stimuli sentences.

Experimental Procedures

The investigator informed the participant about the experimental tasks, his/her right to withdraw from the study at any point without penalty, and that no risk or benefit was associated with participation in the experiment. The investigator asked if the participant was willing to participate and to sign the consent form if he/she agreed. The study began after the consent form was signed.

Experimental Procedures for Speakers. The principal investigator administered the *Mini Mental State Examination (MMSE)* to participants with MS. She explained that this assessment is a commonly used screening tool that assesses different aspects of cognition (e.g., "These questions look at different kinds of thinking."). All participants achieved a score of at least 29 out of 30 on the MMSE. Participants with MS then took part in an interview about their medical history. Finally, recording of the participant's speech began.

Voice Recordings. Voice recordings were made in a quiet laboratory at the Department of Communication Sciences and Disorders of the University of South Florida or in a quiet room in the Morsani Center at the University of South Florida. The participants were recorded with a Cyber Acoustics AC-201 stereo headset with microphone with the microphone 6 cm from the right corner of the participant's mouth. The microphone was connected to a laptop computer and the utterances were recorded directly into Praat (Boersma & Weeninck, 2012).

Before placing the headset on the participant, the experimenter sterilized the headset by thoroughly cleaning it with an alcohol wipe. The microphone was covered with a windscreen and never touched the participants's face or mouth. If the participant was female, the experimenter asked that she pull her hair back before placement of the headset. The experimenter placed the headset on the participant's head and adjusted the microphone so that it was 6 cm from the right corner of the participant's mouth.

The test phrases from the *Assessment of Intelligibility of Dysarthric Speech* and *The Grandfather Passage* were presented to the participants with MS in random order. Each volunteer was given a copy of "The Grandfather Passage" printed in bold Times New Roman, size 26-point font on letter-sized paper. After the participant had a chance to review the paragraph, the investigator instructed the speaker to read the text aloud at a conversational rate. Then, each speaker with MS was presented with a set of 5x8 inch laminated index cards containing two sentences from the *Assessment of Intelligibility of*

Dysarthic Speech. This text also was printed in bold Times New Roman 26 font. Four speech-language pathology students later judged these utterances for intelligibility. To ensure that the intelligibility ratings were not influenced by familiarity with the stimuli sentences, each participant received different sentences from the sentence stimuli set. This ensured that no two participants uttered the same sentences.

Finally, the participants were asked to read the relative timing test phrases following the procedures outlined by Weismer and Fennell (1985). The order of presentation of these stimuli was randomized for each volunteer. The speaker was presented with a set of four 5x8 inch laminated index cards, each containing a stimulus phrase printed in bold Times New Roman 48 point font. The participants were instructed to begin with the top card and read each sentence aloud three times at the target rate before moving on to the next card. Participants were instructed to begin again if they exhibited any disfluencies or pauses during an utterance.

The participant first was instructed to read the sentence three times at a conversational rate of speech (e.g., "Read these sentences at the same speed that you would use in everyday conversation."). After that, the speaker was asked to repeat the phrase three times at a rate that was twice as fast as normal. Then, the speakers were instructed to read the stimuli at a rate half the speed of their conversational speech by extending each word in the sentence, rather than inserting pauses between words. The participants received a model of the ideal rate and were given practice opportunities before recoding. All participants were willing and able to read the stimuli material at the desired rates of speech.

Each phrase and rate was recorded directly into Praat as separate files. The phrases were sampled at 22,050 Hz in accordance with best practices for the computer analysis of recorded speech (Plichta, 2003). Following the final recorded utterance in the stimulus set for each rate, the investigator replayed each audio file on headphones to ensure that each utterance was recorded. If necessary, the participant was instructed to repeat a stimulus item to ensure that the data set was complete.

Measurement Procedures. The second repetition of each phrase was extracted from its recording for analysis. Several measurements were taken from computer-generated spectrograms for each test phrase at each rate of speech. First, the total duration of the utterance was measured from the first glottal pulse to the last. Three ratios were determined by dividing the period (i.e., "a period of articulatory activity"; Prosek, et al., 1988) by the latency (i.e., a unit of speech "within that defined period"; Prosek, et al., 1988). The last ratio was determined by dividing two periods. The requirements for each ratio measurement are described in Table 1 and the specific measurement points for each sentence are listed in Appendix E. Spectrograms for each sentence and ratio are displayed in Appendix F.

As shown in the table below, the demarcation points for the ratio intervals had specific measurement requirements. These points corresponded with instances in the speech wave that are thought to be important to the planning and execution of the utterance (Weismer & Fennell, 1985).

Table 1. General Description of Onset and Offset Points for Relative Timing Ratios.

Ratio	Period Onset	Period Offset	Latency Onset	Latency Offset	Characteristic
A	First glottal pulse of initial vowel	CV or VC junction at ~ ¾ through utterance	First glottal pulse of initial vowel	CV or VC junction at ~ ½ of utterance	Boundaries of period and latency overlap
B	First glottal pulse of initial vowel	CV or VC junction at ~ 2/3 through utterance	First glottal pulse of initial vowel	CV or VC junction at ~ 1/3 through the utterance	Contained within ratio A; boun-daries of period and latency overlap
C	CV or VC junction in middle third of the utterance	CV or VC junction in middle third of the utterance	CV or VC junction in middle third of the utterance	CV or VC junction in middle third of the utterance	Acoustic latency totally contained within acoustic period
D	CV/VC junction at beginning of first third of the utterance	CV/VC junction at end of the first third of the utterance	CV/VC junction at end of 2nd half of the utterance	CV/VC junction at beginning of the 2nd half of the utterance	Boundaries do not overlap

Determination of Intra-judge Reliability. Intra-judge reliability was assessed by random selection and re-analysis of 10% of the stimulus items. This 10% sample was representative of the participant pool, testing sessions, stimulus items, and speaking rates. The primary investigator re-measured these sentences and compared the two sets of measurements to determine the intra-rater reliability coefficient.

Experimental Procedures for Listeners. Four speech-language pathology graduate students provided intelligibility ratings for all speakers. Ratings took place in a quiet room in the Department of Communication Sciences and Disorders at the University of South Florida, Tampa, Florida. The recordings were presented in a set from each speaker (i.e., two sentences from the *Assessment of Intelligibility of Dysarthric Speech* and the Grandfather Passage). Order of presentation was randomized. The recordings were played over headphones from a laptop computer. Listeners transcribed the both sentences from the *Assessment of Intelligibility of Dysarthric Speech*. All speakers with MS were judged to be 100% intelligible.

In addition, four speech-language pathology students rated the MS participant's speech on a visual analog scale (VAS). Two students assessed all eleven participants with multiple sclerosis and a third student assessed the first ten participants. However, a fourth student rated only the eleventh participant due to a scheduling conflict with one of the initial listeners. Participants with MS had their voice, articulation, resonance, and rhythm rated on a 100-point scale. Scores ranged from 9-53, with a mean of 32. The mild-moderate severity rating on the VAS was in contrast to the 100% intelligibility rating noted on the sentences from the *Assessment of Intelligibility of Dysarthric Speech*. This difference reflects noticeable changes in speech/voice production that did not interfere with intelligibility at the time of testing. People with MS have been shown to have a perceptually weaker and/or harsher vocal quality than healthy speakers (Dogan, Midi, Yazici, Kocak, Gunal, & Sehitoglu, 2007).

Statistical Analysis Procedures

Statistical analysis of the data was completed using IBM SPSS Statistics software (IBM Corporation, 2012). A two-way repeated measures ANOVA was computed to determine if the speakers in each participant group (patients with MS vs. healthy controls) were able to produce three speaking rates that were significantly different from one another and reflective of conversational, fast and slow rates. Then, the individual sentences were subjected to a three-way analysis of variance (ANOVA). The independent variables were rate, ratio, and speaker group and the four different ratios served as the dependent variables. Post hoc testing and effect sizes were computed, when appropriate.

Chapter Three: Results

The stability of relative timing measures has been studied in both healthy and impaired speakers at conversational and fast rates (Baum & Boyczuk, 1999; Clark, 1995; Gracco, 1988; Goberman & McMillan, 2005; Ludlow et al., 1987; Max & Caruso, 1997; Robb & Pang-Ching, 1992; Weismer & Fennell, 1985). However, little attention has been paid to the effect of slowed rate on relative timing measures (Clark, 1995). Additionally, few studies have included participants with dysarthria, especially those who exhibit temporal dysregulation.

For this experiment, eleven speakers with multiple sclerosis (MS) and ten healthy controls produced four sentences at three different rates. Sentences were produced three times at each rate and the middle utterance was analyzed for relative timing. The investigator completed a set of nine timing measurements: one for sentence duration and eight others to formulate four timing ratios. The four ratio measurements were then subjected to statistical analysis to determine the effect of speaking rate on the relative timing of speech and to note differences in performance across participant groups. These results will be discussed following a demonstration of measurement reliability.

Reliability of Measurements

The reliability of the data was determined in two ways: verification of sentence rates and ratio measurement reliability. The results of these analyses are presented next.

Confirmation of rate differences. The results of a two-way repeated measures ANOVA on the absolute duration data showed that there was a significant interaction between sentence and rate, $F(6,102) = 11.991$, $p < .001$, $\eta^2 = .414$. Post hoc testing with paired samples t-tests and a Bonferroni correction revealed that the 12 paired comparisons of interest were all significantly different. In other words, all rate conditions were significantly different from one another for each sentence. As shown in Figure 1,the fast condition was always the fastest and the slow condition was always the slowest. These results indicated that the speakers were capable of changing their speaking rate from normal to slow or fast.

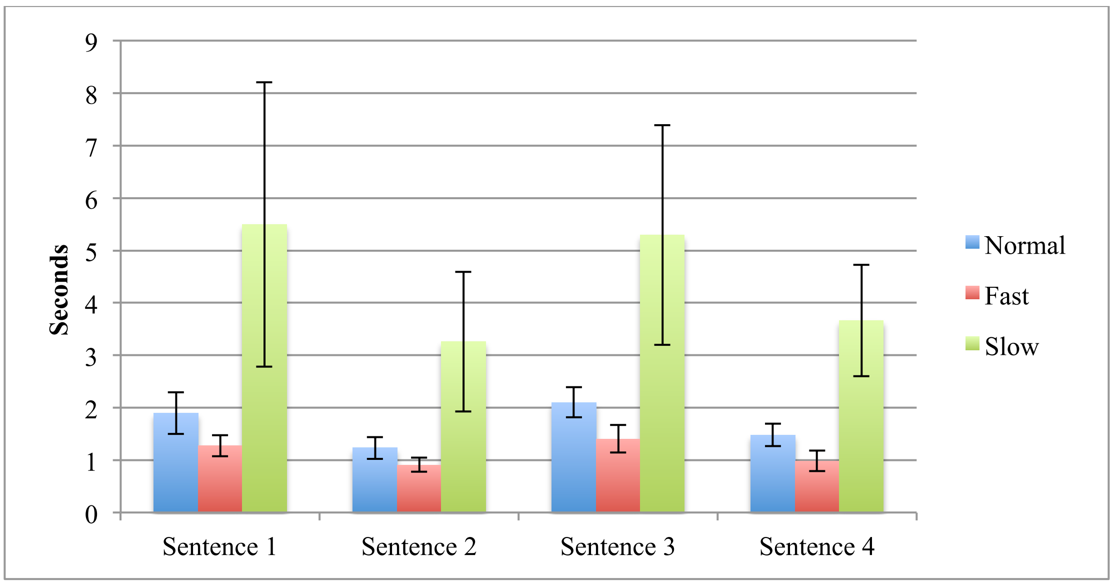

Figure 1. Change in Sentence Duration Across Conversational, Fast, and Slow Rates.

Reliability of acoustic measurements. Intra-judge reliability was determined by having the principal investigator re-measure 10% of the data, representing all rates of speech, sentences, and participant groups. The first and second measurements then were correlated, with a resulting Pearson Product-Moment correlation of r = 1.0. Intra-rater reliability was deemed to be excellent.

Differences Attributable to Rate, Ratio, and Speaker Group.

After the reliability of measurements was determined, the data were subjected to a three-way repeated measures ANOVA, one for each sentence. The independent variables were rate (normal, fast, or slow), ratio type (A, B, C, or D) and speaker condition (MS or control) and the dependent variable was the computed ratio. Analyses were conducted by individual sentence because each sentence differed in phonemic content, sentence length, and number of consonant-vowel (CV) or vowel-consonant (VC) transitions. Three sentences consisted primarily of plosives and fricatives while one sentence contained only plosives. Secondly, sentence length ranged from four to seven words. Another important difference between sentences was the number of CV or VC transitions (e.g., the release of a /p/ into an /o/). These transitions were used as demarcation points for the relative timing ratios and ranged from nine to eighteen points in the stimuli sentences. When a sentence contained fewer of these transitions, the individual ratios shared more boundary points. In view of these variations, differences attributable to phonemic content, length, and transitions were expected. Thus, sentences were analyzed individually to better account for these factors.

As depicted in Table 1, the Ratios measured different portions of the sentence. Ratio A encompassed the first three-quarters of the sentence, while Ratio B encompassed the first two-thirds of the sentence. The middle portion of the sentence was represented by Ratio C. Finally, Ratio D was the only ratio made up of non-overlapping intervals: the first third of the utterance and the final half of the utterance. The results for individual sentences will be presented below.

Sentence 1: "The potato stew is in the pot." The two-way repeated measures ANOVA revealed a significant interaction between rate and ratio, $F(6,114) = 6.353$; $p < .001$, $\eta^2 = .251$. Post hoc testing with paired samples t-tests with a Bonferroni correction (.05/12 = .004) revealed that 2 of the 12 paired comparisons of interest were significant. As illustrated in Figure 2, only Ratio A in the slow condition was significantly different from the normal and fast conditions. This would suggest that for Ratio A, differences in rate were more evident at the beginning of the sentence. No differences were noted across speaker groups.

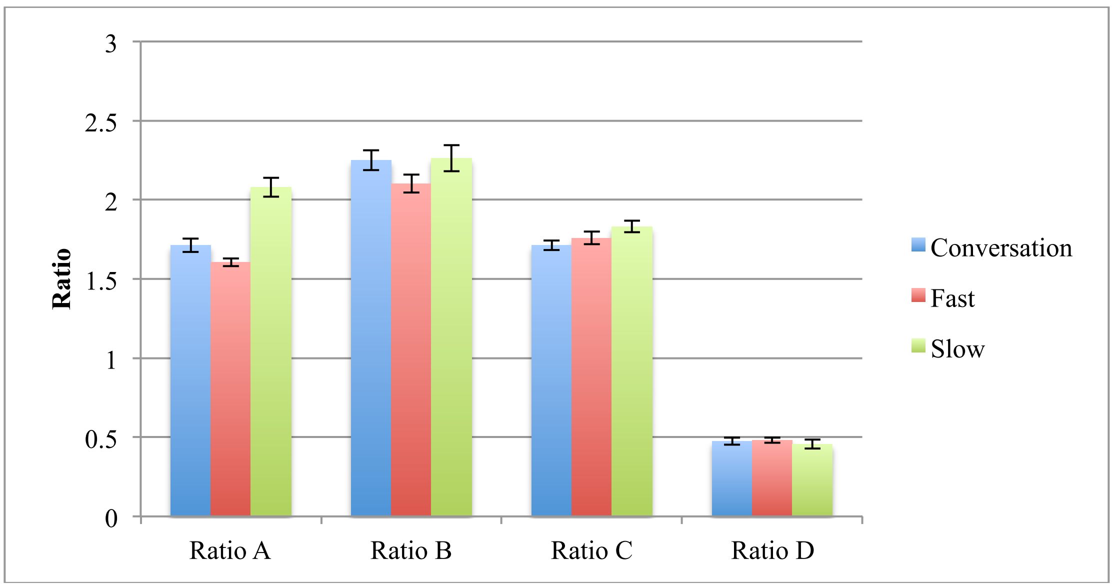

Figure 2. Ratio Data for the Sentence, "The Potato Stew is in the Pot" for All Participants Across Sentence Rates.

Sentence 2: "Buy bobby a puppy." The two-way repeated measures ANOVA revealed a significant interaction between rate and ratio, $F(6,114) = 4.999$; $p < .001$, $\eta^2 = .208$. Post hoc testing with paired samples t-tests with a Bonferroni correction (.05/12 =

.004) indicated that 1 of 12 paired comparisons of interest was significant. As illustrated in Figure 3, the slow condition was significantly different from the fast condition only for Ratio C. This finding would suggest that relative timing remained constant across all rates and all ratios, except for Ratio C in the slow condition. Hence, the middle portion of this sentence was more susceptible to slowing than the rest of the sentence. Again, no differences were noted across speaker groups.

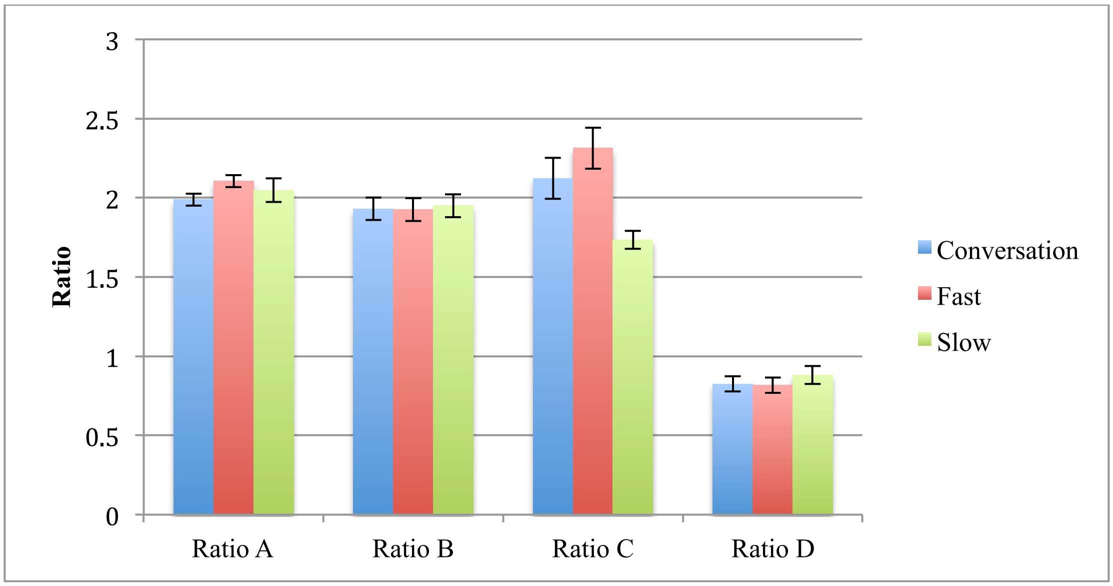

Figure 3. Ratio Data for the Sentence, "Buy Bobby a Puppy" for All Participants Across Rates.

Sentence 3: "Bess bought a book on cooking soup." The two-way repeated measures ANOVA revealed a significant interaction between rate and ratio, $F(6,114) = 13.327$; $p < .001$, $\eta^2 = .412$. Post hoc testing with paired samples t-tests with a Bonferroni correction (.05/12 = .004) revealed that 5 of 12 paired comparisons of interest were significant and three more approached significance. As illustrated in Figure 4, the slow condition in Ratio B was significantly different from the fast condition and it approached significance for the normal condition ($p = .007$). For Ratio C, the fast condition was significantly different from the conversation and slow productions and the difference between the normal and slow conditions approached significance (p = .016). For Ratio D, slow was significantly different from normal and fast conditions and approached significance for the comparison between normal and fast (p = .012). Since relative timing should be constant across sentences, these findings suggest that increased sentence length and phoneme composition may result in increased variability in relative timing across rates and ratios. Interestingly, speaker group also approached significance, $F(1,19) = 4.037$; p =.059, $\eta^2 = .175$ (see Figure 5). This result indicates that speakers with multiple sclerosis demonstrated larger relative timing ratios than controls when sentence length increased. In other words, more time was devoted to articulatory movements than the latency phase in this sentence. However, this is the weakest effect size noted among the findings, suggesting that other factors explained more of the variance in this analysis.

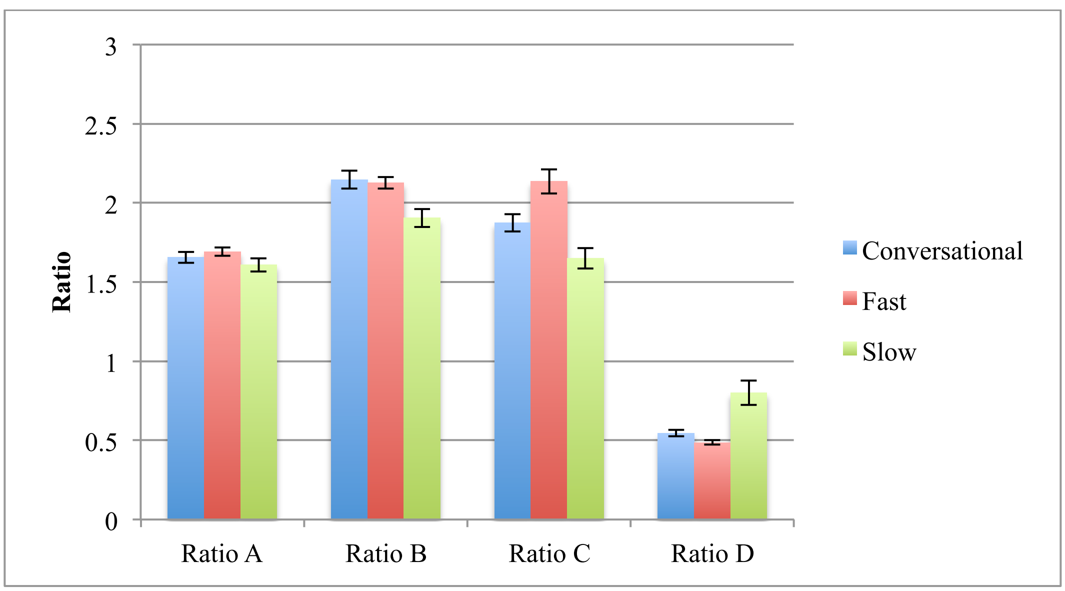

Figure 4. Ratio Data for the Sentence, “Bess Bought a Book on Cooking Soup” for All Participants Across Rates

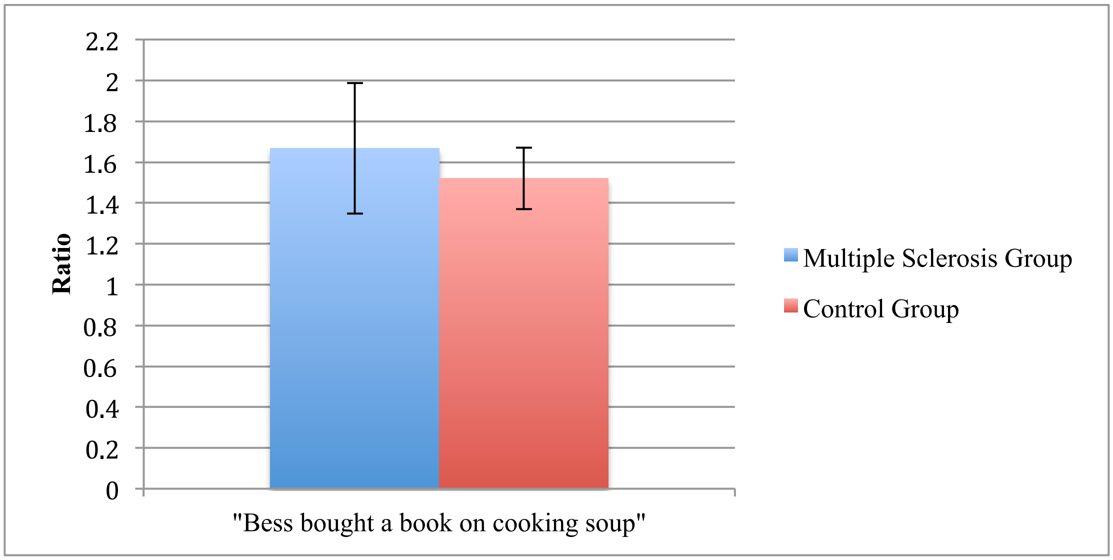

Figure 5. Speaker Group Differences for Averaged Ratio Data Across Rates for "Bess Bought a Book on Cooking Soup".

Sentence 4: "Bob hit the big dog." The two-way repeated measures ANOVA revealed that the interaction between rate and ratio was significant, $F(6,114) = 6.503$; $p < .001$, $\eta^2 = .277$. Post hoc testing with paired samples t-tests with a Bonferroni correction (.05/12 = .004) revealed that 2 out of 12 paired comparisons of interest were significant. As illustrated in Figure 6, the slow condition for Ratio A was significantly different from the normal and fast conditions. In addition, the difference between the normal and slow rates for Ratio D approached significance ($p = .008$). These findings suggest that the rate differences at the beginning and end of this sentence seemed to disrupt relative timing when the rate was changed. In addition, the interaction between condition and ratio was significant, $F(3,51) = 3.469$; $p = .023$, $\eta^2 = .169$. However, this interaction is not of any real interest since other studies have not compared ratios within a sentence. Finally, as illustrated in Figure 7, condition was significant, $F(1,17) = 17.067$; $p = .001$, $\eta^2 = .501$, with the patients with MS displaying larger ratios that the control group. It may be that the number of plosives in this sentence made it more difficult for participants with multiple sclerosis to produce because it required them to rapidly change from a closed vocal tract configuration for the plosive to a more open configuration for the vowel that followed and then to close again. Previous research has suggested that these patients may be less able to produce clearly articulated words that include plosives (Keller, Vigneux, & Laframboise, 1991). Nevertheless, the MS group performed differently from their peers when the articulatory demands of the sentence were increased.

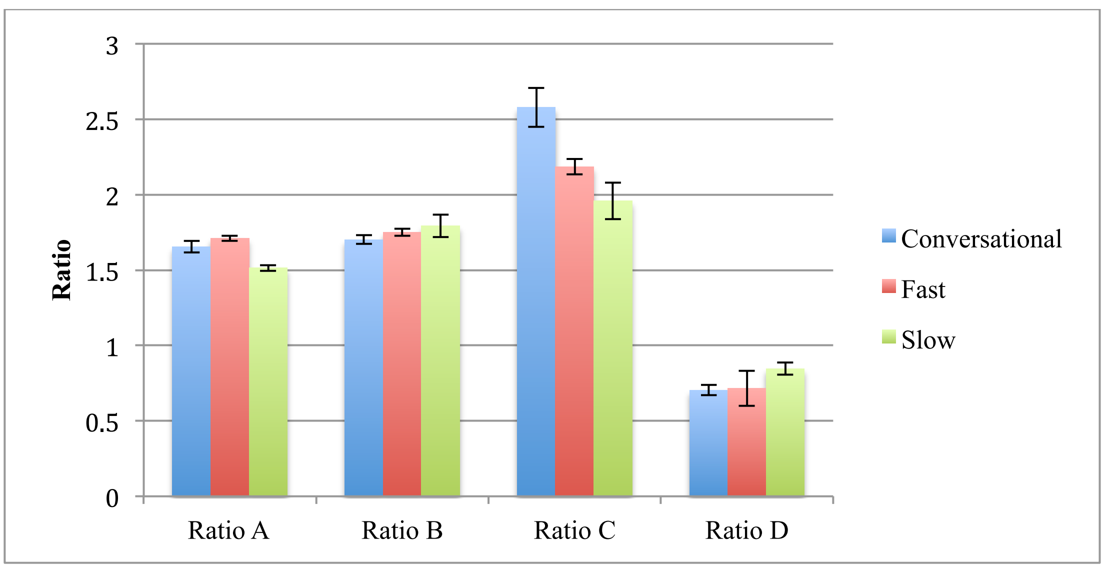

Figure 6. Ratio Data for the Sentence, “Bob hit the big dog” for All Participants Across Rates.

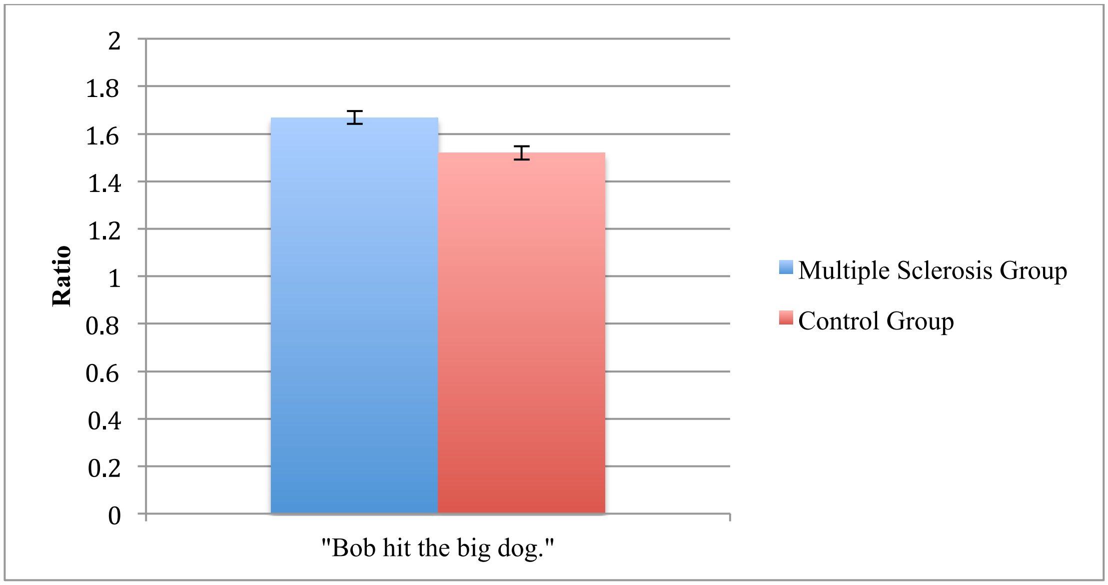

Figure 7. Speaker Group Differences for Averaged Ratio Data Across Rates for "Bob Hit the Big Dog"

Summary of the Statistical Findings.

Analyses were conducted for each sentence individually due to differences in phonemic content, sentence length, and number of consonant-vowel (CV) or vowel-consonant (VC) transitions. As depicted in Table 2, these variations influenced the constancy of the relative timing ratios. Specifically, the increased length of sentence three, "Bess bought a book on cooking soup", greatly increased the variance of relative timing measures among all rates.

Interestingly, sentence three was the only sentence to display variable relative timing in the conversational and fast rates. This may be attributable to its longer sentence length. However, as a whole, relative timing remained constant in the fast and conversational rates. Slowed rate seemed to change the relative timing for at least 1 ratio for all sentences, regardless of length.

Table 2. Instances in which the Slow Rate Differed from Fast or Conversational Rates, Separated by Sentence and Ratio.

	"The potato stew is in the pot."	"Buy Bobby a puppy."	"Bess bought a book on cooking soup."	"Bob hit the big dog."
Ratio A	Slow-fast Slow-normal			Slow-fast Slow-normal
Ratio B			Slow-fast Slow-normal*	
Ratio C		Slow-fast	Slow-fast Slow-normal* Fast- normal	
Ratio D			Slow-fast Slow-normal Normal-fast*	Slow-normal*

** indicates that values approached significance*

Secondly, the main effect of condition was significant for sentence three (i.e., "Bess bought a book on cooking soup") and approached significance for sentence four (i.e., "Bob hit the big dog"). This indicates that participants with multiple sclerosis were more susceptible to variation in articulation, which in turn affected relative timing, as higher-level linguistic processes (e.g., stress rhythm, production complexity, and length) increased the cognitive demands on the motor planning process.

Chapter Four: Discussion

The purpose of this study was to evaluate the relative timing of speech in speakers with MS and their age-matched, healthy peers. Specifically, the investigator wanted to determine the effect of rate change on the stability of relative timing measures. Previous research has established that relative timing remains constant when normal and fast rates are compared, but little is known about what happens when the rate is deliberately slowed (Clark, 1995; Weismer & Fennell, 1985). The second research question addressed how rate changes affected relative timing ratios in individuals with MS, as this neurological impairment is known to affect aspects of speech production, including speech timing.

Overall, the present results support the body of research that has established the constancy of relative timing in fast and conversational rates (Baum & Boyczuk, 1999; Ludlow et al., 1987; Prosek, et al., 1988; Robb & Pang-Ching, 1992; Tuller & Kelso, 1984; Weismer & Fennell, 1985). The present findings also support previous research showing that relative timing is more susceptible to variation while using a slow rate (Clark, 1995), though this effect was inconsistent. The following sections will answer the research questions that consider the influence of rate and speaker condition on the production of relative timing. Then, implications of the current results will be discussed, including possible applications for speech-language intervention. Limitations of the current study will be considered, and suggestions for future research will be made.

Factors that appeared to influence relative timing

The current results revealed that a slow rate affected relative timing in almost a third of the opportunities (12/32 or 4 sentences and 8 comparisons). No one ratio appeared to be influenced more often, suggesting that personal preferences in how to execute the slowed rate may play a role. In particular, the use of vowel lengthening instead of pauses in to produce the slow rate seemed to be important. In addition, the qualities of the vowels themselves were also found to affect the stability of relative timing measures in the slow rate. A more in-depth discussion of these factors follows.

Effect of slow rate on relative timing measures. Previous research has shown that relative timing ratios are more susceptible to variation when rate is slowed, (Clark, 1995). Similar to previous studies, this variation in the slow rate was inconsistent (see Table 2). This inconsistency may be explained by examining the mechanism by which slow rate may alter relative timing.

As discussed previously, speaking rate does not appear to be intrinsic to an utterance, so it can be altered slightly without changing the motor plan for the utterance. For this reason, it can be considered an inessential variable in the motor planning for speech. However, a continuous (i.e., “big enough”) change to an inessential variable will initiate a change to the motor plan (Kugler et al., 1982). In the case of speech, the extension of the vowels during the slow rate may be the large, continuous change that is required to initiate a corresponding modification to the motor plan for the utterance. Furthermore, these changes may have destabilized the intrinsic relative timing of the utterance (Weismer & Fennell, 1985).

Effect of vowel characteristics on relative timing measures. Since the lengthening of vowels appears to be related to relative timing variability, it stands to reason that the qualities of the vowels themselves may be a factor in this change. To be specific, the characteristics of the vowels in sentences 1 and 4 may explain why relative timing varied in the slow rate in some instances.

For the sentence, "The potato stew is in the pot", Ratio A for the slow rate was significantly greater than the normal and fast rates, indicating a slowing down as the sentence progressed. This ratio was determined by dividing the first ¾ of the utterance by the first ½ of the utterance. Phonemic changes in the word "potato" that occurred when rate was slowed may have disrupted the relative timing of this sentence. In the fast and normal rates, the word was pronounced /pʌ.teɾo/ (i.e., with the lax vowel /ʌ/). In the slow rate, participants tended to produce the word as /po.teto/ (i.e., with the tense vowel /o/). Tense vowels have been shown to be longer in duration than lax vowels (House, 1961; Umeda, 1975). This phonemic change in the slow rate may be a contributing factor to the instability of the relative timing for this ratio.

On the other hand, relative timing remained constant across rates for Ratio B. This finding is surprising since Ratio B was contained within Ratio A. Nevertheless, these results are consistent with Clark's (1995) results. She suggested that because Ratio A encompassed a larger portion of the utterance, there were more primary stress points and interstress intervals in the utterance (Clark, 1995). "The potato stew is in the pot" may have been more variable in Ratio A than Ratio B because Ratio A contained more vowels. The increased number of lengthened vowels may have allowed the change in rate to reach the critical value needed to initiate a change in the relative timing.

Similarly, a phonemic change also occurred in the slow rate for sentence 2, "Buy Bobby a puppy". In the conversational and fast rates, the "a" in this sentence was pronounced /ʌ/. This was changed to the longer vowel /e/ in the slow rate. Ratio C, which encompassed the portion of the sentence that included this vowel, reflected the phonemic change in the slow rate. This may be why the relative timing varied in the slow rate for this portion of the sentence.

Similar to sentences 1 and 2, the vowel features in sentence four, "Bob hit the big dog", also influenced the relative timing in the slow rate. Similar to sentences 1 and 2, the vowel features in sentence four, "Bob hit the big dog", also influenced the relative timing in the slow rate. This sentence demonstrated variable relative timing in Ratios A and D. Ratio A encompassed the beginning of the sentence, while Ratio D was made up of two non-overlapping segments at the beginning and end of the sentence. These first and last monosyllables contained long vowels, which may have been where the participants found it easiest to lengthen the vowel.

In conclusion, slow rate affected relative timing in nearly a third of the opportunities. While the effect was inconsistent, all sentences displayed variability in at least one ratio. Lastly, the use of vowel lengthening instead of pauses seemed to be important, as well as the quality of the vowels themselves.

Effect of sentence length on relative timing measures.

As displayed in Table 2, the most variability in relative timing was observed in the sentence, "Bess bought a book on cooking soup". This sentence displayed five significant paired comparisons and three comparisons that approached significance out of a total of twelve comparisons. In this sentence, variability in relative timing ratios may have occurred because of the greater processing demand associated with increased sentence length (Maner, Smith, & Grayson, 2000). Sentence length has been shown to affect the motor programming for an utterance for both healthy and disordered speakers (Kleinow & Smith, 2000; Strand & McNeil, 1996). Specifically, these investigators have shown that sentence length increases the variability of motor movements at the level of the articulators. While this is not directly comparable to relative timing measures, it does lend support to the idea that sentence length disrupts the stability of speech motor planning and execution.

Interestingly, sentence 1 (i.e., “The potato stew is in the pot”) contained the same number of words a sentence 3, but did not display as much variability. This may be explained by the differences in measurement procedures for the two sentences. For sentence 1, measurements began at the second word of the sentence, because of the observed tendency to reduce the word *the* in the fast and conversational rates. Though sentences 1 and 3 differed by only one word, there was a noticeable difference between the variability displayed by these sentences due to this difference in sentence length. Additionally, sentence 1 contained a word that experienced a phonemic change in the slow rate (i.e., “the”), while sentence 3 did not.

Interestingly, the only two significant comparisons between the fast and conversational rates occurred in sentence three. This indicates that increased sentence length may disrupt the stability of relative timing, even in the fast and conversational rates. However, further studies should be conducted before a conclusive statement can be made regarding sentence length.

Conclusions about slowed rate, sentence length, and relative timing.

The current results showed that relative timing was most susceptible to change in the slow rate. This may be due to the change in topological qualities of the motor plan when the continuous change of rate is applied to the utterance. Furthermore, the present findings support the idea that relative timing is generally constant in the fast and conversational rates. In this study, only two of the fourteen significant comparisons occurred between the fast and conversational rates. Notably, these two aberrant results occurred in the same sentence, "Bess bought a book on cooking soup". Ratios from this sentence, which was one of the longest sentences (with a more content words than any other sentence), accounted for over half of the significant comparisons overall. This indicates that increased sentence length and number of content words may disrupt the stability of relative timing, even in the fast and conversational rates.

Differences across groups.

In this study, the relative timing of people with also MS was examined to assess whether this group would demonstrate variable relative timing when compared to their healthy peers. Because temporal dysregulation is characteristic of the dysarthria exhibited by people with MS, it was hypothesized that these individuals may have shown some differences in relative timing even before these individuals begin to experience significant difficulties with speech production. The current results indicated that participants with MS performed differently from their age-matched healthy controls on the sentences, "Bess bought a book on cooking soup" and "Bob hit the big dog". For both sentences, participants with MS had larger ratios than their healthy peers. This indicates that they required more time to execute these utterances at all rates of speech.

Participants with MS may have experienced more difficulty with , “Bess bought a book on cooking soup” because it is one of the lengthier sentences tested. As discussed previously, increased sentence length increases the variability of motor movements because of the increased cognitive demand required to produce these utterances (Maner et al., 2000; Strand & McNeil, 1996). This is true even for speakers with no cognitive impairments. Since people with multiple sclerosis experience cognitive deficits early in the course of the disease, including reduced processing speed and efficiency, it stands to reason that they may experience more difficulty with a more complex speech task (Chiaravalloti & DeLuca, 2008). Interestingly, there were no significant group differences for the sentence, “The potato stew is in the pot” (sentence 1), which had the same number of words as sentence 3. However, measurement procedures differed for these sentences, which may have influenced the results for sentence 1 as compared to sentence 3. Specifically, measurements for sentence 1 began at the second word, while measurements for sentence 3 included every word in the sentence. Also sentence 1 had more content words.

Additionally, the sentences “Buy Bobby a puppy” and “Bob hit the big dog” are also similar in sentence length, but only “Bob hit the big dog” showed a significant difference between groups. While “Bob hit the big dog” is not a linguistically complex sentence, its production requires a succession of subtle articulatory changes that increased the complexity of the motor movements. The complexity of the syllables in this sentence may have been more difficult participants with multiple sclerosis to produce because it required them to rapidly change from a closed vocal tract configuration for the plosive to an open configuration for the vowel that followed to the production of another plosive.

Previous research has shown that people with neurogenic speech disorders are less able to produce clearly articulated words that include plosives (Keller et al., 1991).

Implications of the Current Research

The results of this study demonstrated that relative timing was not constant in the slow rate for either healthy speakers or speakers with multiple sclerosis. Additionally, increased sentence length contributed to the variability of relative timing ratios across all rates. Lastly, people with multiple sclerosis demonstrated different relative timing than their healthy peers when producing lengthier or motorically complex sentences.

Consistent with previous research, the current results showed that relative timing ratios were more susceptible to variability when rate was slowed, though relative timing was largely maintained in the fast and conversational rates (Clark, 1995). These results suggest that a reduced rate may have triggered the critical change required to alter the relative timing. This change may also correspond to a topological shift in the planning of the utterance. If so, slowed speech may allow the impaired speaker to create the motor plan for speech in a different cortical area than for fast or conversational rates.

Clinically, the motor program underlying slowed speech is of interest because rate reduction training is the most commonly used, though poorly understood, evidence-based treatment for dysarthria (Hartelius, Nord & Buder, 1995; Liss, et al., 2009; Pilon, McIntosh, & Taut, 1998; Tjaden & Wilding, 2004; Yorkston, et al., 2007). Interestingly, people with dysarthria have been shown to have slower speech segments than their healthy peers (Hartelius, et al., 1995; Weismer & Fennell, 1985). So how does slowing down already slower-than-normal speech make a person more intelligible?

Research has suggested that people with dysarthria habitually speak near their maximum rate - i.e., they are speaking ‘as fast as they can’, though this rate is still slower than their healthy peers (Jaeger, Hertrich, Stattrop, Schonle, & Ackermann, 2000; McHenry, 2003). In other words, they are utilizing a motor plan for their pre-morbid conversational or fast rates. The plan created for the formally intact muscular system is carried out by a weak, spastic, or temporally dysregulated system and the result is less intelligible (or unintelligible) speech. It may be that slowed speech allows the dysarthric speaker to access a motor plan better suited to his impaired muscular system.

Though slowed rate appears to change the relative timing of an utterance, higher level linguistic processes may also lead to variability in relative timing, even in fast and conversational rates. As these processes (e.g., stress rhythm, syntactic complexity, and length) are integrated into the motor plan for an utterance, they may decrease the stability of relative timing measures. Additionally, for these longer or more complex sentences, participants with MS displayed different relative timing ratios from their healthy peers. Therefore, people with MS may benefit from strategies that break longer or more complex sentences into more manageable “chunks”. This may make these sentences more manageable for this population, which may improve their intelligibility overall. More research is needed to determine the efficacy of these treatment suggestions. Finally, these subtle changes in timing, which have appeared in MS speakers without dysarthria, may point to more severe timing abnormalities for these patients as their disease progresses.

Procedural Observations and Limitations

Though this group of people with MS showed some differences in relative timing from their healthy peers, it is important to note that they did not exhibit dysarthria at the time of testing. Intelligibility was rated at 100% for each participant with MS and none showed significant signs of cognitive impairment, which has been correlated with dysarthria in MS (Hartelius et al., 2000; Mackenzie & Green, 2009). Therefore, the inclusion of MS patients with more severe dysarthria may yield more significant results, though concomitant cognitive impairments may negatively affect this group's ability to participate in future research about their speech.

Additionally, a more in-depth analysis of the MS participants could have been completed to determine if any groups of MS symptoms correlate with timing characteristics. For example, it was thought that patients with cerebellar lesions may exhibit more unstable relative timing. However, this hypothesis was not tested because the researcher was not able to determine which patients were exhibiting cerebellar lesions from the limited medical history obtained at the patient interview. A more thorough review of the patients' medical history, along with a standardized measure of their disability status [e.g., the *Kurtzke Expanded Disability Scale*, (Kurtzke, 1983)] may have allowed the validity of this hypothesis to be assessed.

Additionally, a more sensitive mental status measure may have revealed cognitive differences between subjects with MS. Since many of the participants had attended or had been referred for speech-language therapy because of short-term memory impairments or word-finding difficulties, it would not have been surprising if this group had displayed some level of cognitive impairment. It may have been the case that the MMSE was not sensitive enough to detect subtle cognitive difficulties. This information is relevant to the study because dysarthria in MS often co-occurs with cognitive impairment (Mackenzie & Green, 2009).

Furthermore, while the visual analog scale (VAS) used to judge the speech of the MS participants has been shown to be a sensitive measure for people with progressive neurological diseases (Sussman & Tjaden, 2012), it may not have been the best choice for the present study. The scale asks the rater to judge the overall speech/voice production of the sample (e.g., voice, resonance, articulatory precision, and rhythm). This may explain why many of the participants were rated as moderately impaired on the VAS, but were rated 100% on the intelligibility scale. It may be that the factors unrelated to the study, such as vocal quality or resonance, were disproportionally represented on the VAS scale. A better solution may have been to adapt this scale so that each feature (e.g., voice, resonance, etc.) was rated separately. Secondly, it would be preferable if the same three people had rated each participant to ensure consistency of the ratings. Lastly, only the speech of participants with MS was assessed. A better method would have been to assess the speech of all participants (i.e., including the healthy speakers) to better compare the participants with MS with the healthy controls.

Furthermore, while all participants were able to slow their rate by extending the vowels, this effect was inconsistent across participants. In other words, some people easily slowed their rate by lengthening the vowels, while other participants required multiple models. More time could have been devoted to instructing the participants about the desired slowed rate and more opportunities for practice could have been given to ensure more consistency among participants. Additionally, a comparison could have been made between slowed speech characterized by pauses and slowed speech characterized by lengthened vowels. This may have been a better method to test the hypothesis that lengthened vowels in the slow rate disrupt relative timing measures.

Recommendations for Further Research

The results of the present study have added to the body of research about relative timing in both healthy and impaired speakers (Baum & Boyczuk, 1999; Clark, 1995; Ludlow et al., 1987; Prosek, et al., 1988; Robb & Pang-Ching, 1992; Tuller & Kelso, 1984; Weismer & Fennell, 1985). However, there is still much to be explained about the role of relative timing in speech. In both normal and impaired speakers, the effect of slowed rate should be further examined to determine if this change in rate corresponds to a topological change in cortical processing. Studies that utilize functional neuroimaging technologies may better test this hypothesis. Secondly, more research is needed that includes people with varying degrees of neurological impairment affecting speech to determine its effect on relative timing. Lastly, more information is needed about the effect of lengthened vowels versus use of pauses in the disruption of relative timing in the slow rate. As suggested in previous studies, a more in-depth look at these factors may clarify the role of timing characteristics in the planning and programming of speech (Clark, 1995).

References Cited

Ackermann H., & Hertrich, I. (1994). Speech rate and rhythm in cerebellar dysarthria - An acoustic analysis of syllabic timing. *Folia Phoniatrica Et Logopaedica, 46*, 70-78.

Baum, S., & Boyczuk, J. (1999). Speech timing subsequent to brain damage: Effects of utterance length and complexity. *Brain and Language, 61*, 30-45.

Bent, T., Bradlow, A., & Smith, B. (2008). Production and perception of temporal patterns in native and non-native speech. *Phonetica*, *65*, 131-147.

Boersma, P., & Weenink, D. (2012). *Praat: Doing phonetics by computer* . (5.3.23 ed.)

Brookshire, R. (2007). *Introduction to neurogenic communication disorders,* (7th ed.). St. Louis: Mosby Elsevier.

Byrd, D. (1996). A phase window framework for articulatory timing. *Phonology, 13*, 139-169.

Chiaravalloti, N., & DeLuca, J. (2008). Cognitive impairment in Multiple Sclerosis. *The Lancet Neurology*, *7*, 1139 – 1151.

Clark, H. (1995) The reliability of relative timing measures. University of South Carolina, Columbia, SC. Unpublished master's thesis.

Corey-Bloom, J., & David, R. (2009). *Clinical adult neurology*. New York: Demos Medical.

DeLuca, J., & Nocentini, U. (2011). Neuropsychological, medical and rehabilitative management of persons with Multiple Sclerosis. *Neurorehabilitation, 29*, 197-219.

Denes, P. & Pinson, N. (1963). *The speech chain: The physics and biology of spoken language.* Garden City, NY: Anchor Books.

Dogan, M., Midi, I., Yazici, M., Kocak, I. Gunal, D., Sehitoglu, M. (2007). Objective and subjective evaluation of voice quality in Multiple Sclerosis. *Journal of Voice, 21*, 735 – 740.

Drugs.com (2000-2013). Retrieved June 17, 2013 from www.drugs.com

Duffy, P. (2005). *Motor Speech Disorders: Substrates, differential diagnosis, and management.* (2nd ed.) St. Louis: Mosby.

Fink, B. (1986). Complexity, *Science*, *231,* 319 - 325.

Folstein, M., Folstein, S., & McHugh, P. (1975). " Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189 -198.

Gay, T. & Hirose, H. (2009). Effect of speaking rate on labial consonant production. *Phonetica, 27,* 44-56.

Gay, T., & Ushijima, T. (1975). Effect of speaking rate on stop consonant-vowel articulation. In G. Fant (ed.). *Processes in Speech Communication Seminar* (pp. 205 – 209). Stockholm: Almqvist and Wiksell.

Goberman, A., & McMillan, J. (2005). Relative speech timing in Parkinson's Disease. *Communication Sciences & Disorders, 32*, 22-29.

Gracco, V. (1988). Timing factors in the coordination of speech movements. *The Journal of Neuroscience, 8*, 4628-4639.

Hartelius, L., Nord, L., & Buder, E. (1995). Acoustic analysis of dysarthria associated with Multiple-Sclerosis. *Clinical Linguistics & Phonetics, 9*, 95-120.

Hartelius, L., & Lillvik, M. (2003). Lip and tongue function differently affected in individuals with Multiple Sclerosis. *Folia Phoniatrica Et Logopaedica, 55*, 1-9.

Hartelius, L., Runmarker, B., & Andersen, O. (2000). Prevalence and characteristics of dysarthria in a Multiple-Sclerosis incidence cohort: Relation to neurological data. *Folia Phoniatrica et Logopaedica, 52*, 160 – 177.

Hartelius, L., & Svensson, P. (1994). Speech and swallowing symptoms associated with Parkinson’s disease and Multiple Sclerosis: A survey. *Folia Phoniatrica et Logopaedica*, *46*, 9-17.

Haugen, E. (1949). Phoneme or prosodeme? *Language, 25*, 278 - 282.

Henrich, J., Lowit, A., Schalling, E., & Mennen, I. (2006). Rhythmic disturbance in ataxic dysarthria: A comparison of different measures and speech tasks. *Journal of Medical Speech-Language Pathology, 14*, 291-296.

Heuer, H. (1988). Testing the invariance of relative timing: Comment on Gentner (1987). *Psychological Review, 95*, 552 -557.

Heuer, H. (1991). Invariant relative timing in motor-program theory. In P. Wolff & J. Fagard (Eds.). *The development of timing control and temporal organization in coordinated action.* (pp. 37-68). Amsterdam: Elsevier Publishers B.V.

Heuer, H., & Schmidt, R. (1988). Transfer of learning among motor patterns with different relative timing. *Journal of Experimental Psychology, Human Perception and Performance, 14*, 241-252.

House, A. (1961). On vowel duration in English. *The Journal of the Acoustical Society of America, 33*, 1174 - 1178.

IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

Jaeger, M., Hertrich, I., Stattrop, U., Schonle, P. & Ackermann, H. (2000). Speech disorders following severe traumatic brain injury: Kinematic analysis of syllable repetitions using electromagnetc articulography. *Folia Phoniatrica et Logopaedica, 52*, 187 – 196.

Keller, E., Vigneux, P., & Laframboise, M. (1991). Acoustic analysis of neurologically impaired speech. *International Journal of Language and Communication Disorders, 26*, 75-94.

Kent, R. (2000). Research on speech motor control and its disorders: A review and prospective. *Journal of Communication Disorders, 33*, 391 - 428.

Kent, R. & Rosen, K. (2004). Motor control perspectives on motor speech disorders. In B. Maasen, W. Hultsijn, R. Kent, H. Peters, and P. van Liesholt (Eds.), *Speech motor control in normal and disordered speech* (pp. 285 – 311) London: Oxford Press.

Kent, R., Kent, J., Weismer, G., & Duffy, J. (2000). What dysarthrias can tell us about the neural control of speech. *Journal of Phonetics, 28,* 272-302.

Klatt, D. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *The Journal of the Acoustical Society of America, 59*, 1208 – 1221.

Kleinow, J., & Smith, A. (2000). Influences of length and syntactic complexity on the speech motor stability of the fluent speech of adults who stutter. *Journal of Speech, Language & Hearing Research, 43*, 548 - 559.

Kugler, P., Kelso, J., & Turvey, M. (1982). On the control and coordination of naturally developing systems. In J. Kelso & J. Clark (Eds.), *The development of movement control and coordination* (pp. 5- 78). Chicester, England: Wiley

Kurtzke, J. (1983). Rating neurologic impairment in Multiple Sclerosis: An expanded disability status scale (EDSS). *Neurology*, *33*, 1444–1152.

Liss, J., White, L., Mattys, S., Lansford, K., & Lotto, A. (2009). Quantifying speech rhythm abnormalities in the dysarthrias. *Journal of Speech, Language, and Hearing Research, 52*, 1334-1352.

Lofqvist, A. (1994). Proportional timing in speech motor control. *Journal of Phonetics, 19*, 343-350.

Lublin, F. & Reingold, D. (1996). Defining the clinical course of Multiple Sclerosis. *Neurology, 46*, 907 – 911.

Ludlow, C., Connor, N., & Bassich, C. (1987). Speech timing in Parkinson's and Huntington's disease. *Brain and Language, 32*, 195 – 214.

Maas, E., Robin, D., Hula, S., Freedman, S., Wulf, G., Ballard, K., & Schmidt, R. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech-Language Pathology, 17*, 277- 298.

Maassen, B., & Van Lieshout, & Pascal H. (2010). *Speech motor control : New developments in basic and applied research*. Oxford: Oxford University Press.

Mackenzie, C., & Green, J. (2009). Cognitive-linguistic deficit and speech intelligibility in chronic progressive Multiple Sclerosis. *International Journal of Language and Communication Disorders, 44*, 401-420.

Maner, K., Smith, A., & Grayson, L. (2000). Influences of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech, Language, and Hearing Research, 43*, 560 – 573.

Max, L., & Caruso, A. (1997). Acoustic measures of temporal intervals across speaking rates: Variability of syllable- and phrase-level relative timing. *Journal of Speech, Language, and Hearing Research, 40*, 1097-1110.

McHenry, M. (2003). The effect of pacing strategies on the variability of speech movement sequences in dysarthria. *Journal of Speech, Language, and Hearing Research, 46*, 702 – 710.

Neel, A. (2008). Vowel space characteristics and vowel identification accuracy. *Journal of Speech, Language, and Hearing Research, 51*, 574-585.

Pilon, M., McIntosh, K., & Thaut, M. (1998). Auditory vs visual speech timing cues as external rate control to enhance verbal intelligibility in mixed spastic-ataxic dysarthric speakers: A pilot study. *Brain Injury, 12*, 793-803.

Plichta, B. (2003). Best practices in the acquisition, processing, and analysis of acoustic speech signals. Retrieved August 10, 2012, from . *http://www. historicalvoices. org/flint/extras/Audio-technology. pdf.*

Prosek, R., Montgomery, A., & Walden, B. (1988). Constancy of relative timing for stutterers and nonstutterers. *Journal of Speech and Hearing Research, 31*, 654-658.

Rabiner, L., Schafer, R., & Flanagan, J. (1971). Speech Synthesis by Concatenation of Formant‐Coded Words. *The Journal of the Acoustical Society of America*, *49*, 124 - 124.

Robb, M. & Pang-Ching, G. (1992). Relative timing characteristics of hearing-impaired speakers. *Journal of the Acoustical Society of America, 91*, 2954-2960.

Schöner, G. (2002). Timing, clocks, and dynamical systems. *Brain and Cognition*, *48*, 31-51.

Shaffer, L. (1982). Rhythm and timing in skill. *Psychological Review, 89*, 109 – 122.

Smith, B., Wasowicz, J., & Preston, J. (1987). Temporal characteristics of the speech of normal elderly adults. *Journal of Speech and Hearing Research, 30*, 522-529.

Stathapoulous, E., Duchan, J., Sonnenmeier, R., & Bruce, N. (1985). Intonation and pausing in deaf speech. *Folia Phoniatrica, 38*, 1-12.

Strand, E., & McNeil, M. (1996). Effects of length and linguistic complexity on temporal acoustic measures in apraxia of speech. *Journal of Speech, Language and Hearing Research, 39*, 1018-1033.

Sussman, J. & Tjaden, K. (2012). Perceptual measures of speech from individuals with Parkinson's disease and Multiple Sclerosis: Intelligibility and beyond. *Journal of Speech, Language, and Hearing Research, 55*, 1208 – 1219.

Terzuolo, C., & Viviani, P. (1980). Determinants and characteristics of motor patterns used for typing. *Neuroscience, 5*, 1085-1103.

Tjaden, K., & Wilding, G. (2004). Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 47*, 766-783.

Tuller, B., & Kelso, J. (1984). The timing of articulatory gestures - Evidence for relational invariants. *Journal of the Acoustical Society of America, 76*, 1030-1036.

Tye-Murray, N. (1987). Effect of vowel context on the articulatory closure postures of deaf speakers. *Journal of Speech and Hearing Research, 30*, 411 – 417.

Umeda, N. (1975). Vowel duration in American English. *The Journal of the Acoustical Society of America, 58*, 434 - 445.

van Riper, C. (1963). *Speech Correction* (4th ed.) Englewood Cliffs, NJ: Prentice Hall.

van Liesholt, P. (2004). Dynamical systems theory and its application to speech. In B. Maassen et al. (Eds.), *Speech motor control in normal and disordered speech* (pp. 51-84). Oxford: Oxford University Press.

Viviani, P., & Terzuolo, C. A. (1982). On the relation between word-specific patterns and the central control model of typing: A reply to Gentner. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 811-813.

Wallace, S. (1989). *Perspectives on the coordination of movement.* Amsterdam: North-Holland.

Weismer, G., & Fennell, A. (1985). Constancy of (acoustic) relative timing measures in phrase-level utterances. *Journal of the Acoustical Society of America, 78*, 49-57.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale-Revised*. San Antonio: Psychological Corporation.

Yorkston, K., Beukelman, D., & Traynor, C. (1984). *Assessment of intelligibility of dysarthric speech.* Tigard: CC Publications.

Yorkston, K., Hakel, M., Beukelman, D., & Fager, S. (2007). Evidence for effectiveness of treatment of loudness, rate, or prosody in dysarthria: A systematic review. *Journal of Medical Speech-Language Pathology, 15*, xi-xxxvi.

Yorkston, K., Klasner, E., Bowen, J., Ehde, D., & Gibbons, L. (2003). Characteristics of Multiple Sclerosis as a function of the severity of speech disorders. *Journal of Medical Speech-Language Pathology, 11*, 73 - 84.

Appendices

Appendix A : Information about MS Participants

Table 1A. Age, Gender and Limited Medical History of Participants with Multiple Sclerosis

Patient	Age & Gender	Years since Diagnosis	Course of MS	Prescriptions
1	Female - 62	28	Relapsing-Remitting	Baclofen Tysavry
2	Female – 62	19	Relapsing-Remitting	Avonex Gabapentin Baclofen
3	Female - 45	2	Relapsing-Remitting	Avanox Tizanidine
4	Female 59	4	Relapsing – Remitting	Nuvigil Copaxon Baclofen Cymbalta Zoloft Dopomax
5	Female- 47	7	Relapsing – Remitting	Baclofen Copaxon Avanes Topomax
6	Male – 52	13	Relapsing – Remitting	Copaxum Avapentin Hydrocodone Tramadol
7	Female – 48	21	Relapsing – Remitting	No medication at time of testing
8	Female – 57	13	Relapsing – Remitting	No medication at time of testing.
9	Female 58	2	Relapsing – Remitting	Rebif Baclofen Lyrica Fluoxetine
10	Female – 38	21	Relapsing – Remitting	Copaxon Simvastin Amypyra Lexapro Tylenol III

Appendix A : Information about MS Participants (Continued)

11	Female - 58	20	Relapsing – Remitting	Copaxon Avapentin.

Appendix B : Possible Side Effects of Medications Taken By MS Group

Table 2A: Medication Purpose and Possible Side Effects that May Affect Speech Production.

Medication	Use	Common Side Effects That Could Affect Speech	Rare Side Effects That Could Affect Speech
Amypyra	Increases walking speed for patients with MS	NA	NA
Avonex / Rebif	Reduces likelihood of relapses and progression of MS symptoms.	NA	NA
Baclofen	Reduces spasticity	NA	Slurred Speech (<1%) Xerostomia (<1%)
Copaxone	Reduces the frequency of relapse of MS symptoms.	NA	Speech Disorder (1%) Laryngospasm - 1%
Cymbalta	Reduces symptoms of depression and anxiety.	NA	NA
Fluoxetine	Reduces depression and anxiety.	NA	NA
Gabapentin	Reduces seizures	NA	NA
Hydrocodone	Relieves moderate – severe pain.	NA	NA
Lexapro	Reduces depression or anxiety.	NA	NA
Lyrica	Reduces seizures	NA	Speech disorder (7%)
Nuvigil	Promotes wakefulness	NA	Xerostomia (4%)
Tizanidine / Zanaflex	Reduces spasticity	Xerostomia (50%)	NA
Tramadol	Pain Reliever	NA	NA
Topamax	Reduces Seizures	NA	NA
Zoloft	Reduces symptoms of depression and anxiety.	Xerostomia (20%)	NA

Drugs.com. Web. 08 Mar. 2013.

Appendix C: Interview Questions for Participants with Multiple Sclerosis

1. When were you first diagnosed with MS?

2. What was your first symptom?

3. Have you received any surgical interventions for MS?

4. What medications do you take or have you taken for MS?

5. Have you have any stroboscopies (a stroboscopy takes a video of how your vocal folds move when you speak)?

Appendix D : Instructions to Listeners for Visual Action Scale (VAS)

"You will be hearing samples of paragraph readings that for the most part, are highly understandable. We want you to rate the overall severity of the speech sample. Some speakers have neurological diagnoses (e.g., have diseases like Parkinson's Disease or Multiple Sclerosis) and some do not. Please pay attention to the following things when you listen to the passages:

1) Voice (quality– breathy, noisy, gurgly, high pitch, too low pitch or OK)
2) Resonance (too nasal, not nasal in the right places, sounds like they have a cold, or OK)
3) Articulatory precision (some sounds are crisp or slurred or somewhere in between or OK), and
4) Speech rhythm (the timing of speech doesn't sound right or is OK).

In other words, pay attention to overall speech naturalness and prosody (melody and timing of speech). Do not focus on the speaker's intelligibility or how understandable each passage is. Rather, scale your overall impression of the speech/voice output from 'No impairment (at the bottom of the scale) to 'Severely Impaired (at the top)."

Taken from:

Sussman, J. & Tjaden, K. (2012). Perceptual measures of speech from individuals with Parkinson's disease and Multiple Sclerosis: Intelligibility and beyond. *Journal of Speech, Language, and Hearing Research, 55*, 1208 – 1219.

Appendix E: Ratio Measurement Dimensions

This is a listing of the boundary dimensions used for each sentence and each Ratio (A-D) in the present study. The duration and the acoustic period/acoustic latency (i.e., for Ratios A-C) or acoustic period/acoustic period (i.e., for Ratio D) are noted in parenthesis.

Table 3A. Ratio Measurement Dimensions for “The potato stew is in the pot”

Ratio	Period Onset	Period Offset	Latency Onset	Latency Offset
A	/p/ burst in potato	last glottal pulse of /ɪ/ of “in”	/p/ burst in potato	first glottal pulse of /u/ in “stew
B	/p/ burst in potato	last glottal pulse of /ɪ/ of “is”	/p/ burst in potato	last glottal pulse of /o/ of “potato”
C	last glottal pulse of /ə/ ‘potato’	last glottal pulse of /ə/ of second “the”	last glottal pulse of /o/ of “potato”	last glottal pulse of /ɪ/ at “in”
D	/p/ burst in potato	last glottal pulse of /o/ in “potato”	first glottal pulse of /u/ in “stew	last glottal pulse of /ɑ/ in “pot”

Appendix E: Ratio Measurement Dimensions (Continued)

Table 4A. Ratio Measurement Dimensions for “Buy Bobby a Puppy”

Ratio	Period Onset	Period Offset	Latency Onset	Latency Offset
A	First formant of /aɪ/ in “buy”	First formant of /i/ in “puppy”	First formant of /aɪ/ in “buy”	First formant of /i/ in bobby
B	First formant of /aɪ/ in “buy”	First formant of /ʌ/ in “puppy”	First formant of /aɪ/ in “buy”	Last formant of /a/ in “bobby’
C	First formant of /a/ in “bobby”	Last formant of /ʌ/ in “puppy”	First formant of /i/ in bobby	First formant of /ʌ/ in “puppy”
D	First formant of /aɪ/ in “buy”	Last formant of /a/ in “bobby’	First formant of /i/ in “bobby”	First formant of /i/ in “puppy”

Appendix E: Ratio Measurement Dimensions (Continued)

Table 5A. Ratio Measurement Dimensions for "Bess bought a book on cooking soup"

Ratio	Period Onset	Period Offset	Latency Onset	Latency Offset
A	First glottal pulse of /ɜ/ in "Bess"	Last glottal pulse of /ʊ/ in "cooking"	First glottal pulse of /ɜ/ in "Bess"	Last glottal pulse of /ʊ/ in "book"
B	First glottal pulse of /ɜ/ in "Bess"	First glottal pulse of /ʊ/ in "cooking"	First glottal pulse of /ɜ/ in "Bess"	Last glottal pulse of /ʌ/ in "bought a"
C	Last glottal pulse of /ʌ/ in "bought a"	Last glottal pulse of /ʊ/ in "cooking"	First glottal pulse in /ʊ/ in "book"	Last glottal pulse of /ɑ/ in "on cooking"
D	First glottal pulse of /ɜ/ in "Bess"	Last glottal pulse of /ʌ/ in "bought a"	Last glottal pulse of /ʊ/ in "book"	Last glottal pulse of /u/ in "soup"

Appendix E: Ratio Measurement Dimensions (Continued)

Table 6A. Ratio Measurement Dimensions for “Bob hit the big dog”

Ratio	Period Onset	Period Offset	Latency Onset	Latency Offset
A	First glottal pulse of /ɑ/ in “bob”	First glottal pulse of /ɑ/ in “dog”	First glottal pulse of /ɑ/ in “bob”	Last glottal pulse of /ə/ in “the”
B	First glottal pulse of /ɑ/ in “bob”	First glottal pulse /ɪ/ in “big”	First glottal pulse of /ɑ/ in “bob”	Last glottal pulse of /ɪ/ in “hit”
C	Last glottal pulse of /ɪ/ in “hit”	First glottal pulse of /ɑ/ in “dog	First glottal pulse of /ə/ in “the”	Last glottal pulse in /ɪ/ of “big
D	First glottal pulse of /ɑ/ in “bob”	Last glottal pulse of /ɪ/ in “hit”	Last glottal pulse of /ə/ in “the”	Closure of /g in “dog”

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D.

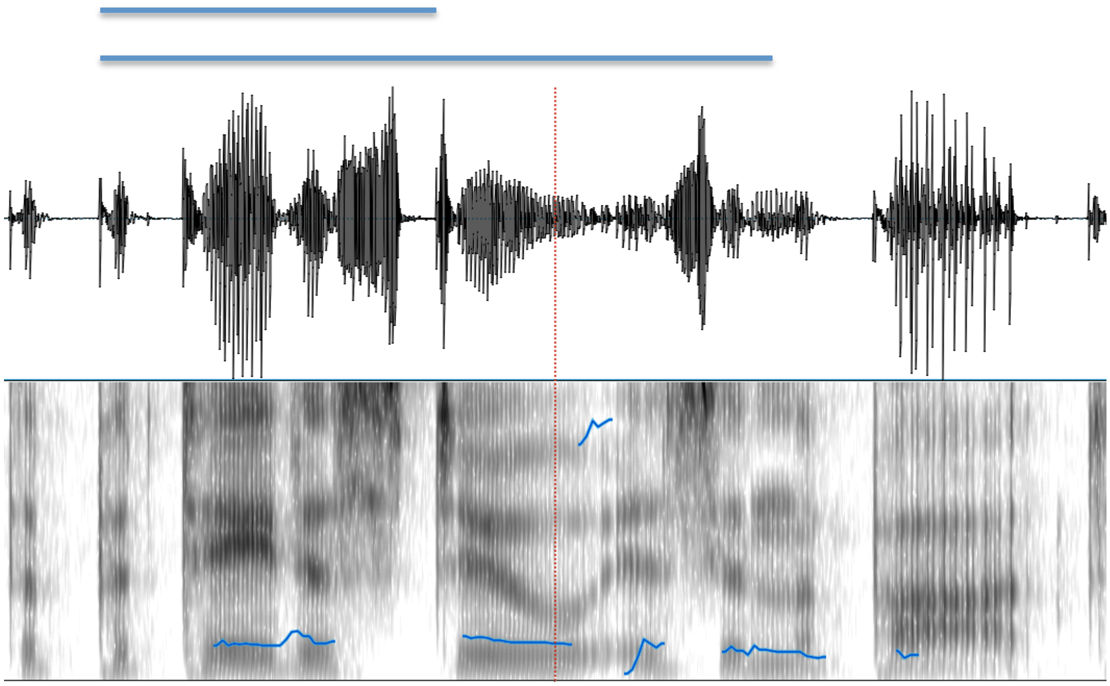

Figure 1A: Spectrogram of "The potato stew is in the pot" produced at a normal speaking rate, showing intervals used to construct Ratio A.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

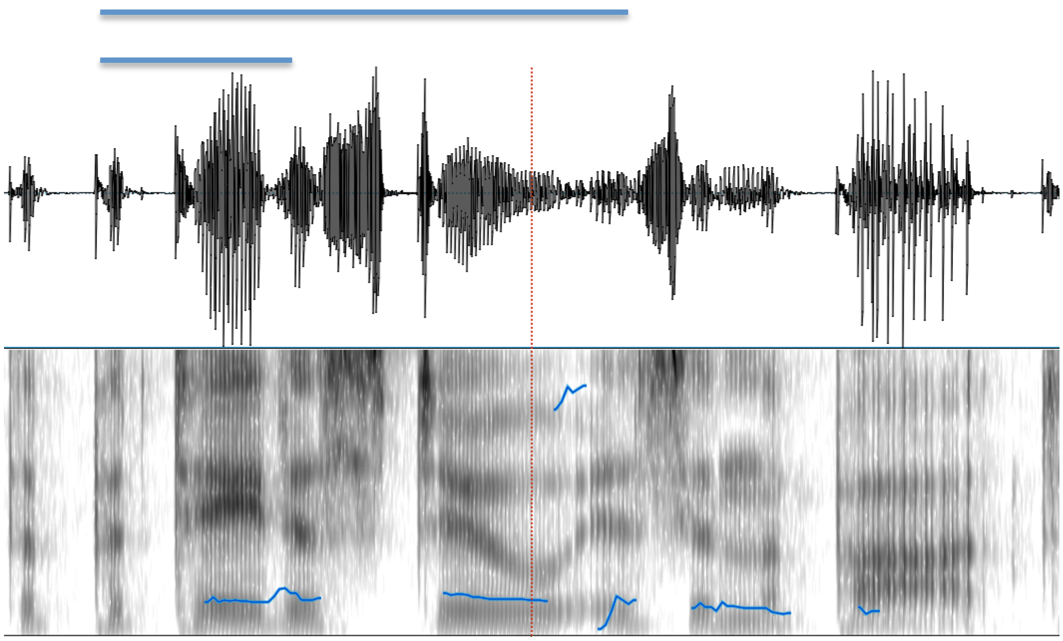

Figure 2A. Spectrogram of “The potato stew is in the pot” produced at a normal speaking rate, showing intervals used to construct Ratio B.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

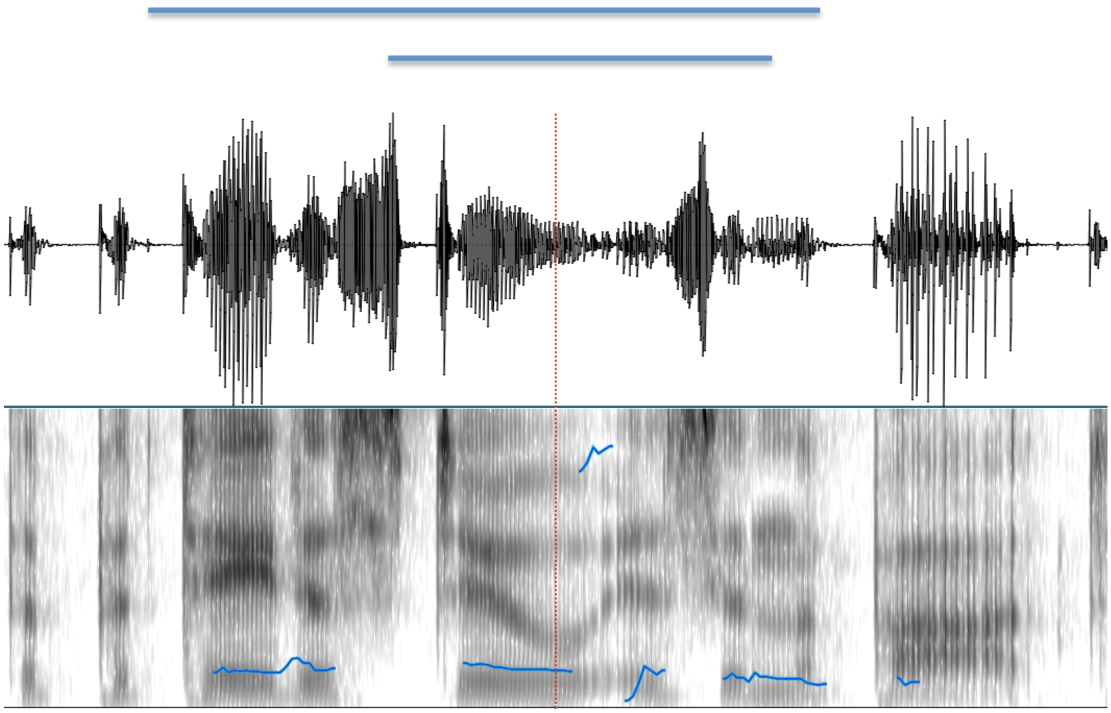

Figure 3A. Spectrogram of “The potato stew is in the pot” produced at a normal speaking rate, showing intervals used to construct Ratio C.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

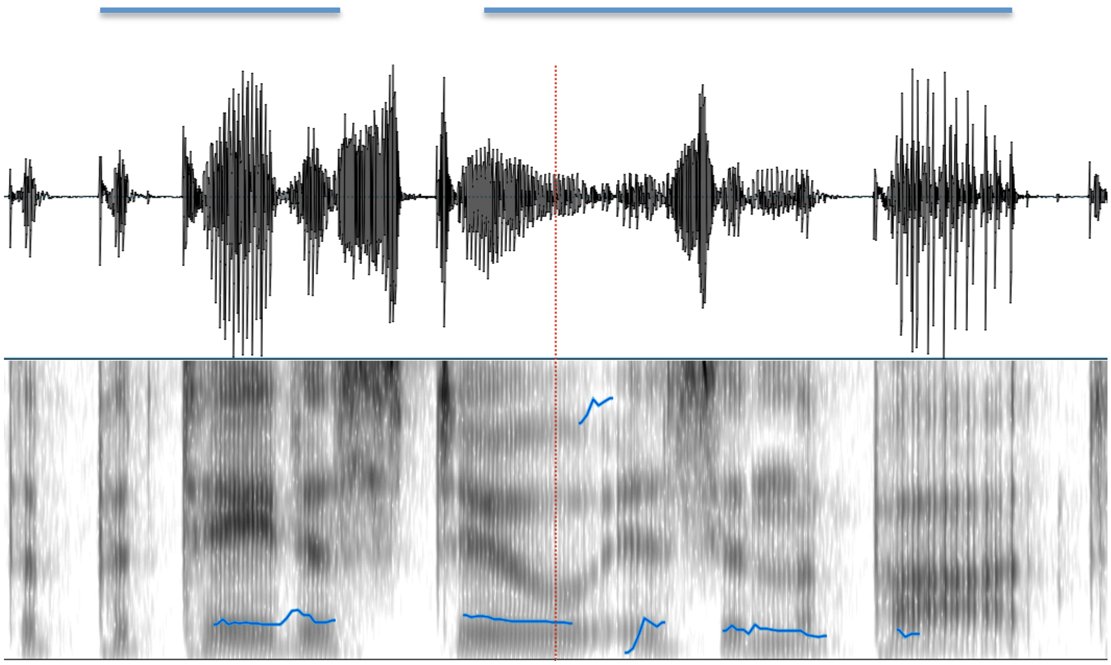

Figure 4A. Spectrogram of "The potato stew is in the pot" produced at a normal speaking rate, showing intervals used to construct Ratio D.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

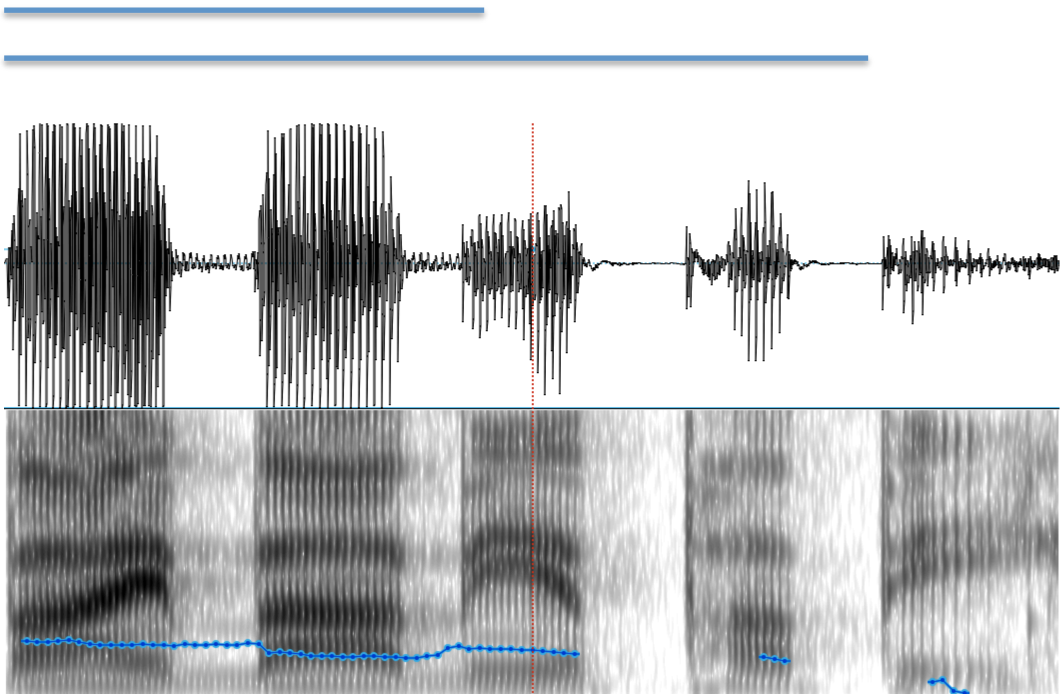

Figure 5A. Spectrogram of "Buy Bobby a puppy" produced at a normal speaking rate, showing intervals used to construct Ratio A.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

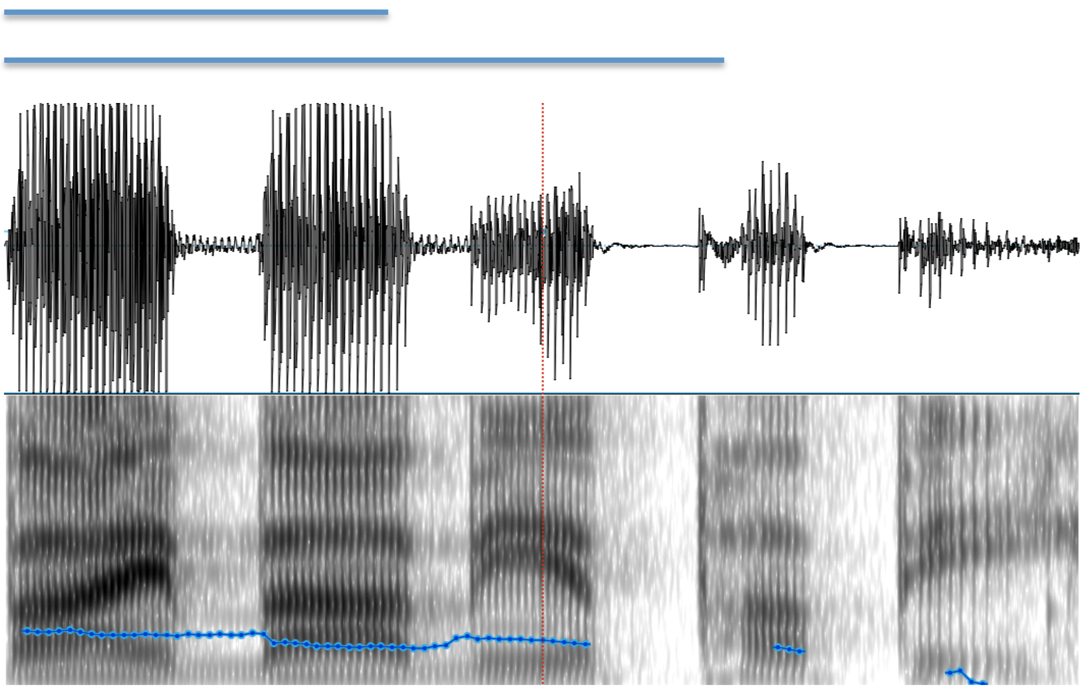

Figure 6A. Spectrogram of “Buy Bobby a puppy” produced at a normal speaking rate, showing intervals used to construct Ratio B.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

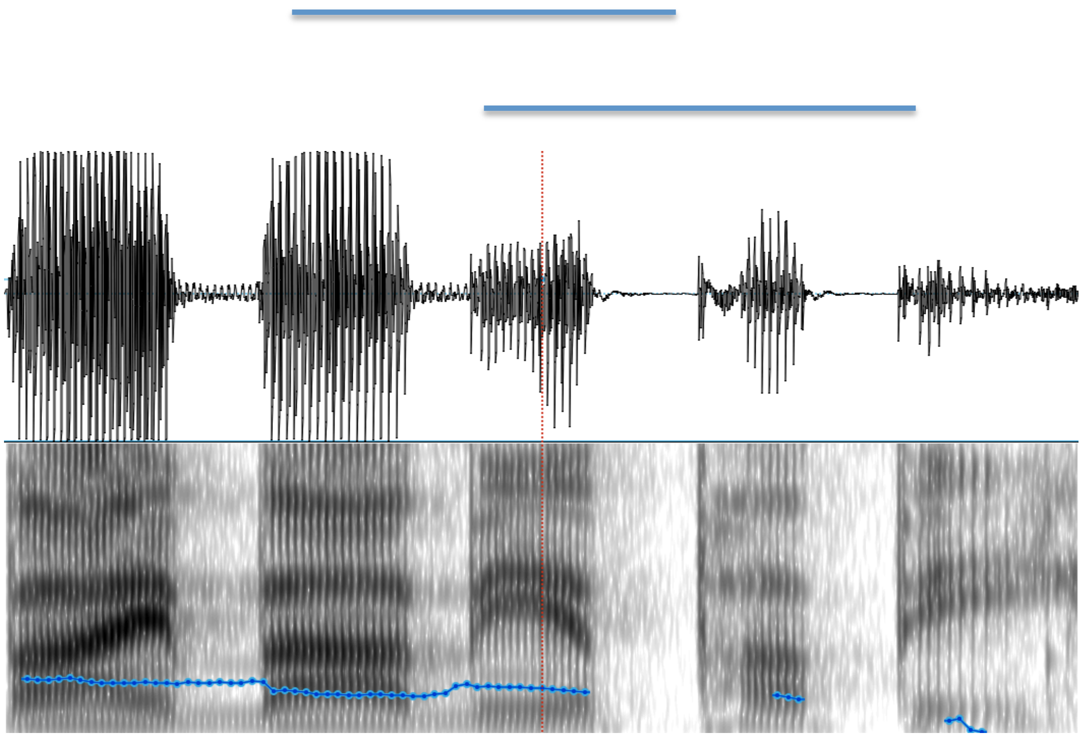

Figure 7A. Spectrogram of “Buy Bobby a puppy” produced at a normal speaking rate, showing intervals used to construct Ratio C.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

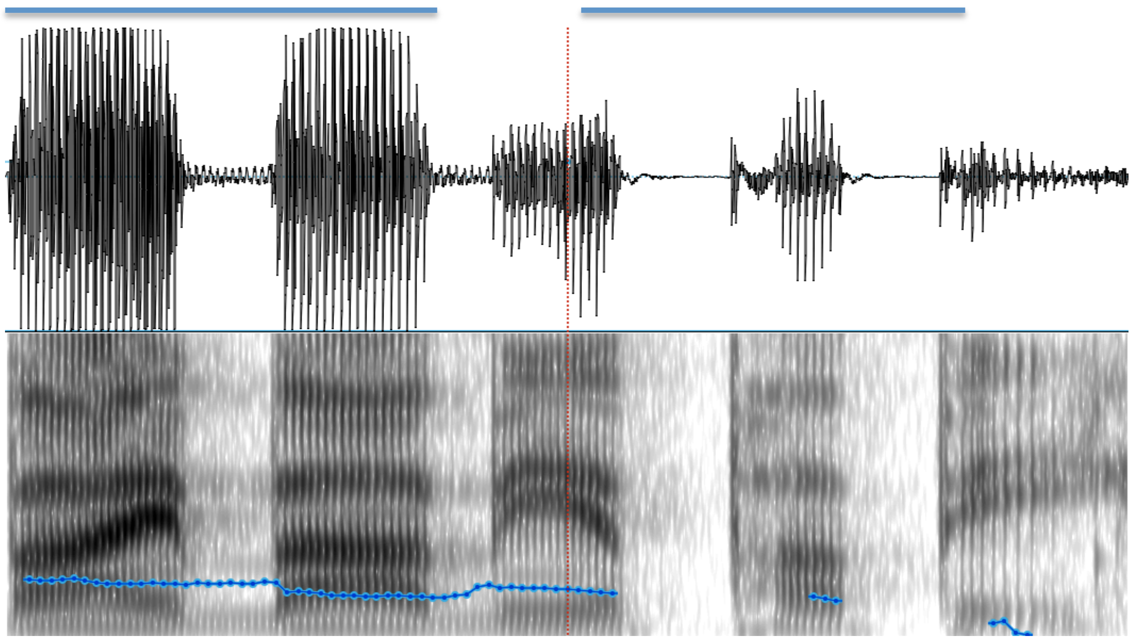

Figure 8A. Spectrogram of "Buy Bobby a puppy" produced at a normal speaking rate, showing intervals used to construct Ratio D.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

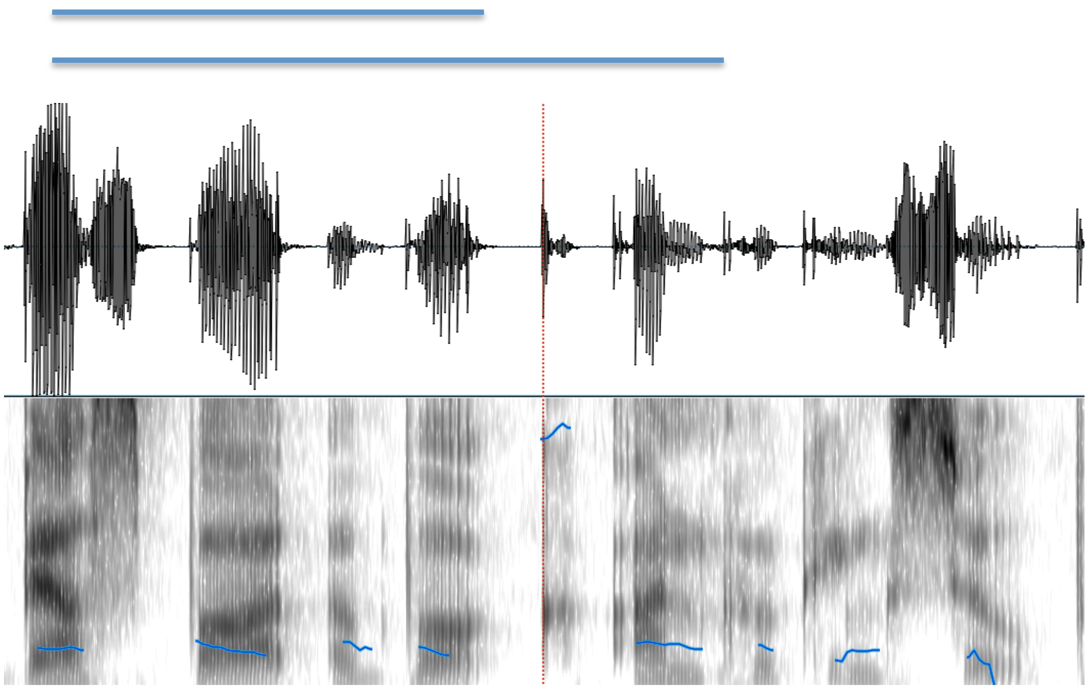

Figure 9A. Spectrogram of "Bess bought a book on cooking soup" produced at a normal speaking rate, showing intervals used to construct Ratio A.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

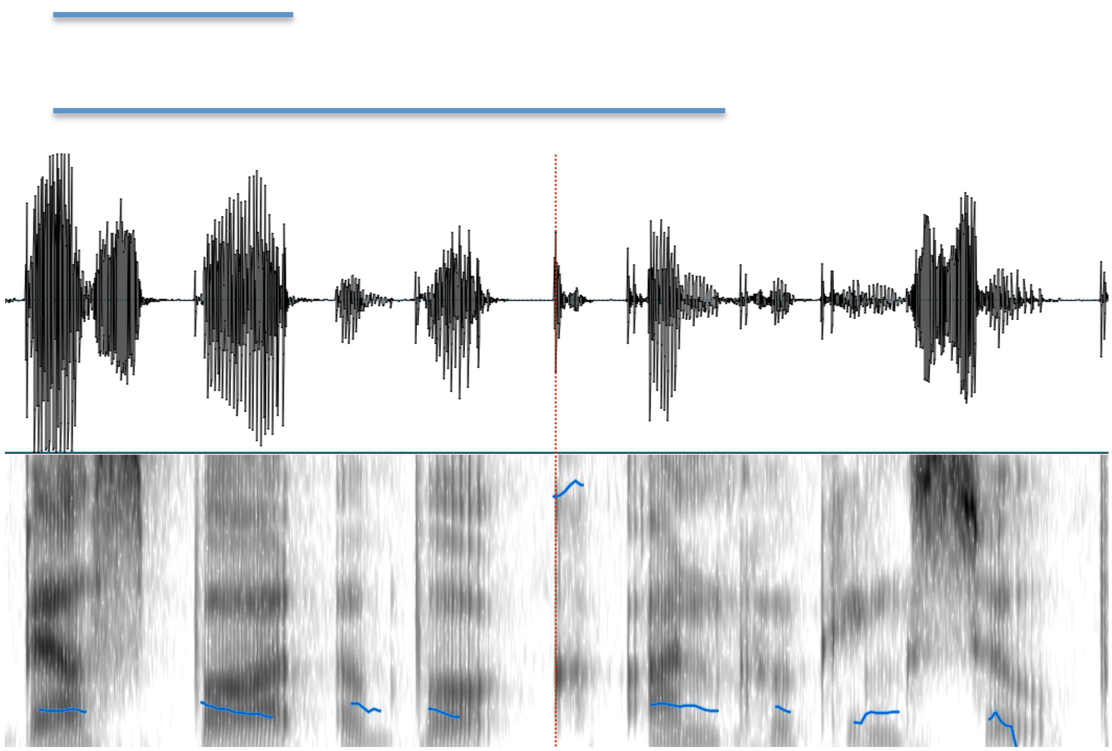

Figure 10A. Spectrogram of "Bess bought a book on cooking soup" produced at a normal speaking rate, showing intervals used to construct Ratio B.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

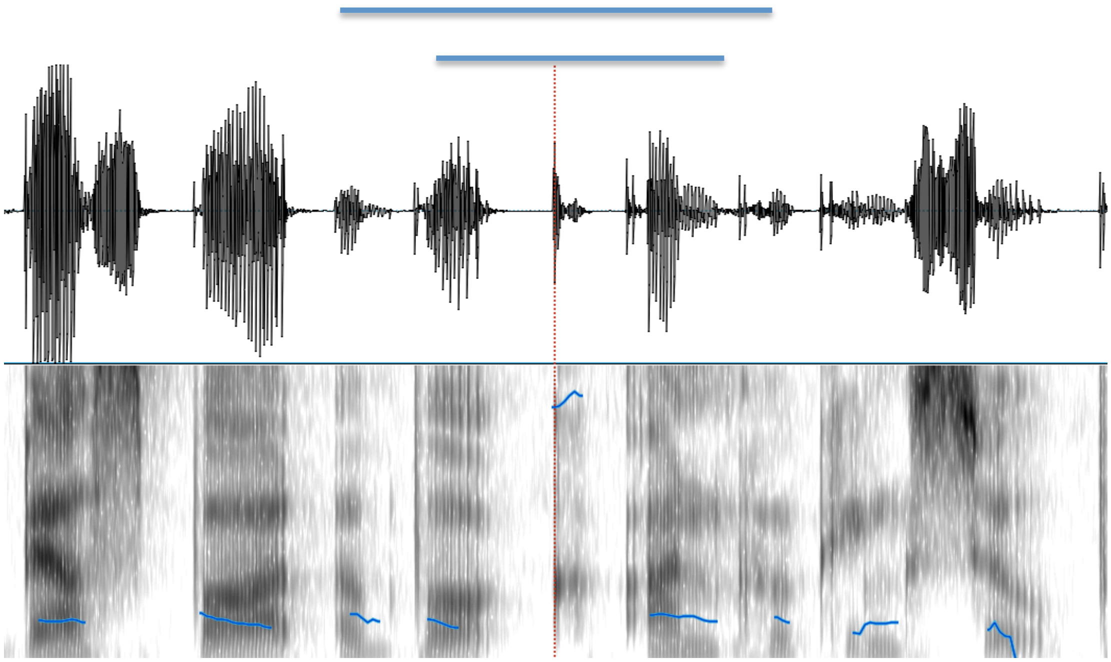

Figure 11A. Spectrogram of “Bess bought a book on cooking soup” produced at a normal speaking rate, showing intervals used to construct Ratio C.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

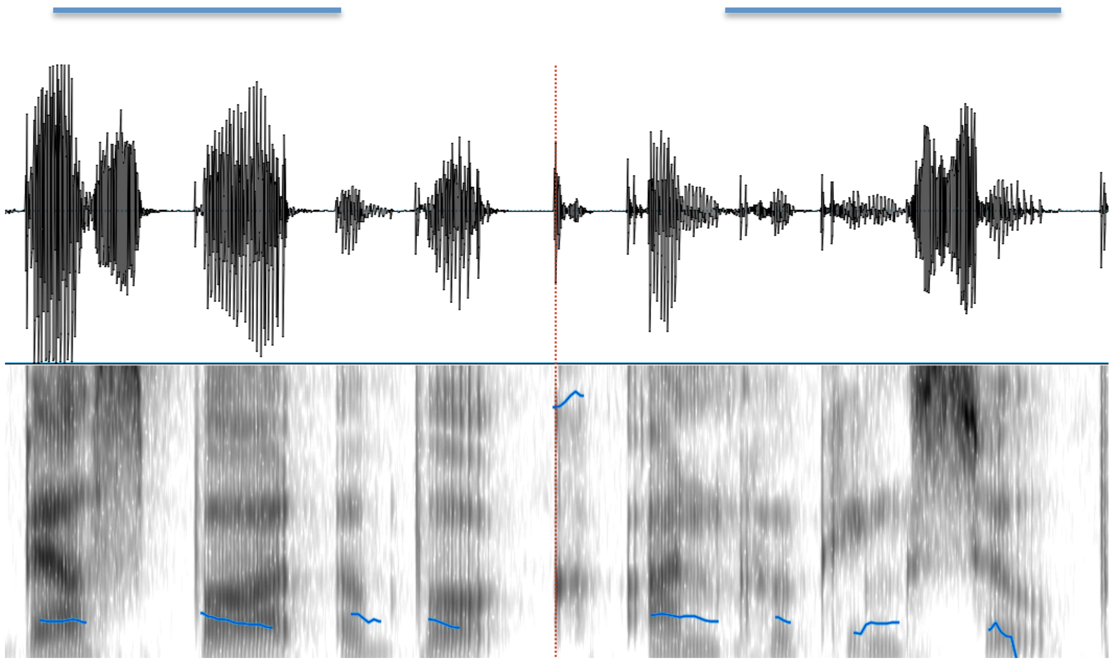

Figure 12A. Spectrogram of “Bess bought a book on cooking soup” produced at a normal speaking rate, showing intervals used to construct Ratio D.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

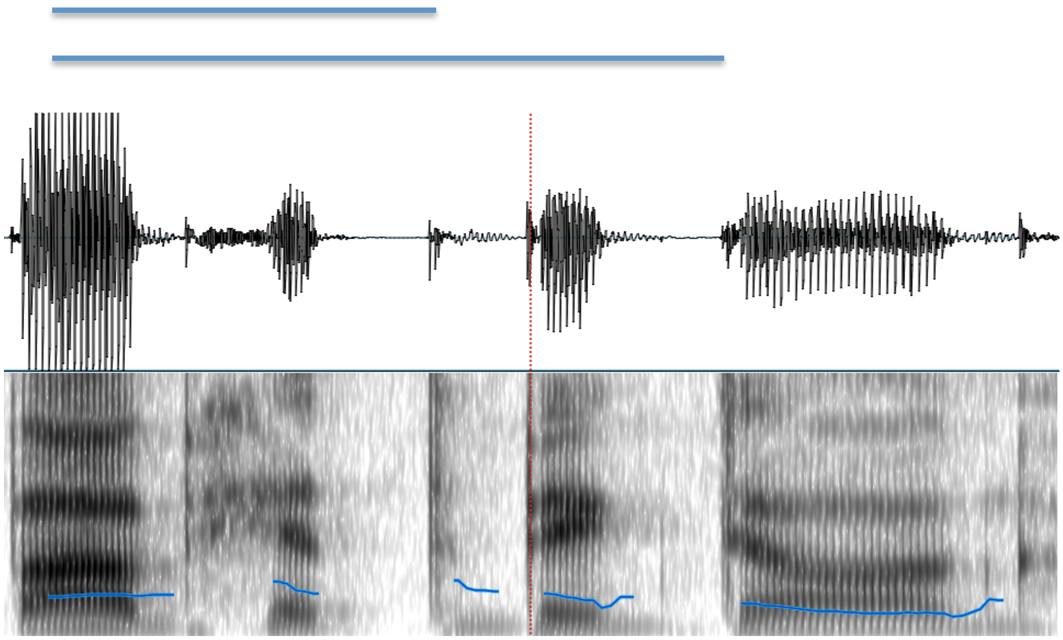

Figure 13A. Spectrogram of “Bob hit the big dog” produced at a normal speaking rate, showing intervals used to construct Ratio A.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

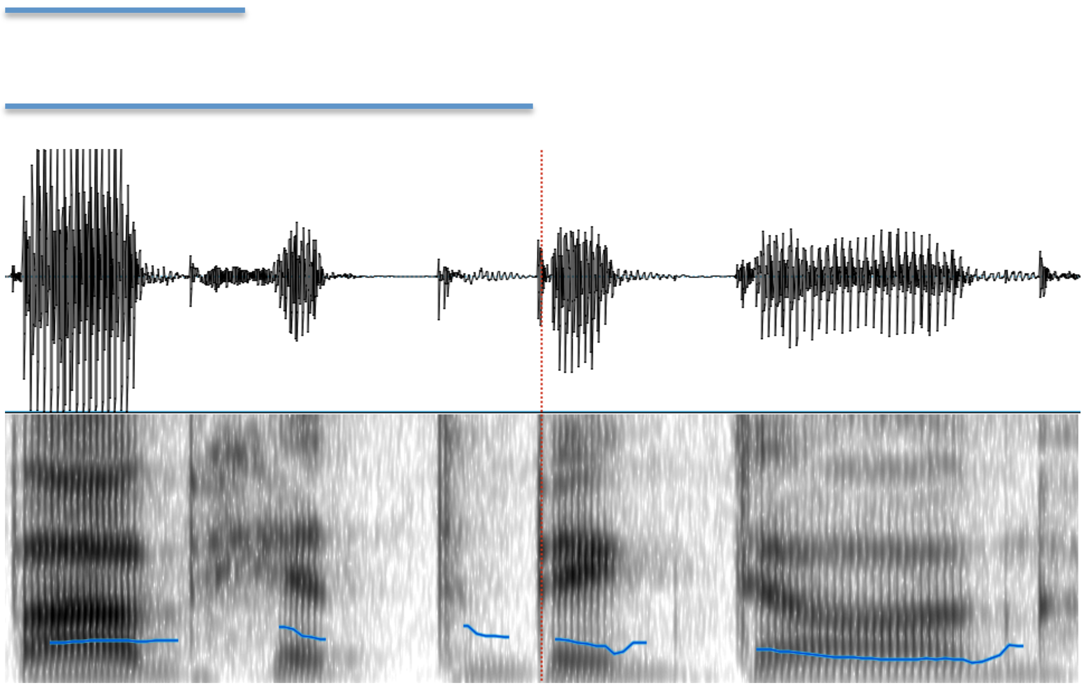

Figure 14A. Spectrogram of "Bob hit the big dog" produced at a normal speaking rate, showing intervals used to construct Ratio B.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

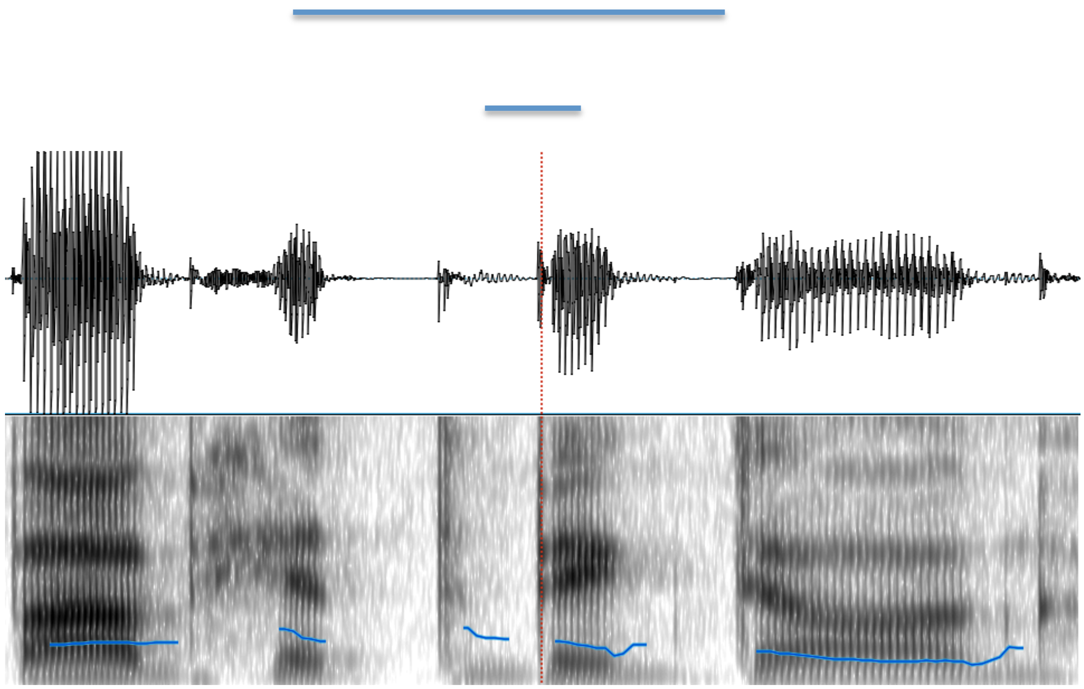

Figure 15A. Spectrogram of “Bob hit the big dog” produced at a normal speaking rate, showing intervals used to construct Ratio C.

Appendix F: Spectrograms of the Four Stimulus Sentences Produced at Normal Rate, Showing the Intervals used in the Construction of Ratios A, B, C, and D. (Continued)

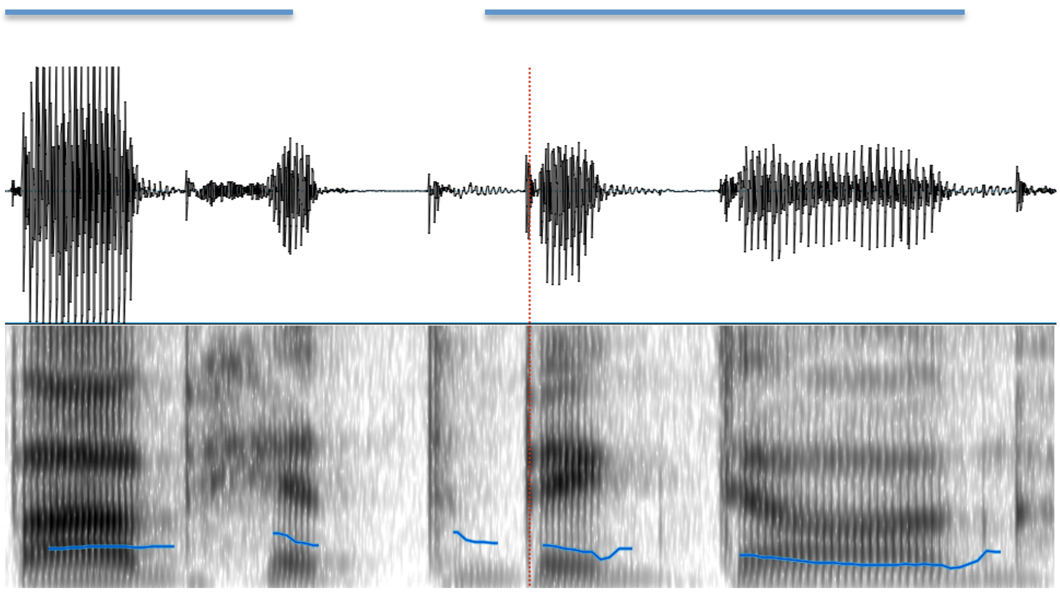

Figure 16A. Spectrogram of “Bob hit the big dog” produced at a normal speaking rate, showing intervals used to construct Ratio D.